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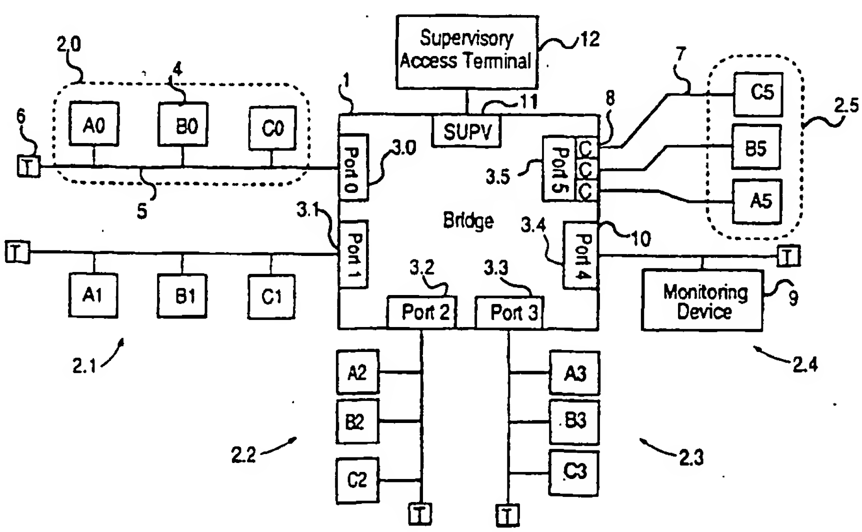

(57) Abstract

A multi-port packet-based bridge (1) is described in which packet transmissions on particular ports or between ports may be monitored on another monitoring port (10). Efficient operation is realized by using a multi-processor environment and data structures that allow a packet received on one port to be transmitted to multiple ports without being "copied" multiple times. By using a Supervisory Access Terminal (12), it is possible to specify various circumstances under which a packet will be sent to the monitoring port (10). These circumstances include monitoring of all packets incoming to a selected port (or ports), all packets forwarded to a selected port (or ports), and packets generated internally and sent to a selected port (or ports). In addition, all packets forwarded from one selected port to another selected port may be monitored. Port monitoring is supported by particular data structures that promote efficient dispatching of packets and by a Bridging Cache (83) that retains the results of recent dispatch calculations. Similar techniques are applied to multi-port routers.

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COMMUNICATION APPARATUS AND METHODS

FIELD OF INVENTION

This invention relates to packet oriented multi-port bridges and routers and, in particular, to the monitoring of packet traffic arriving at the bridges and routers or generated internally.

DESCRIPTION OF RELATED ART

Multi-port bridges and routers allow the connection of two or more packet-based networks of possibly different types. Information in such networks is transmitted by means of packets, each containing data and appropriate addressing information. The purpose of the bridge or router is to relay packets between network segments (a process called forwarding) so that stations connected to different network segments may communicate. An example of a packet-based network protocol is that implemented by the IEEE 802.3 Ethernet standard.

Larger networks can be built by using multiple bridges, routers, or combinations thereof, and the extent and topology of a multi-bridge or multi-router network can be quite complex. Even small single-bridge networks can exhibit complex behavior which may affect performance, security or other aspects of network operations. Analysis of such issues and their correction is usually the responsibility of a network manager, who must examine transmissions on the network and make adjustments to network parameters.

Monitoring of packet networks can be carried out with monitoring devices such as Sniffer™ from Network General of Menlo Park, California or LANalyzer™ from Novell, Inc. of Provo, Utah. These devices are connected to the

network medium, such as coaxial cable, and examine each network transmission regardless of the actual destination of the packets. Typically, network monitors provide the capability of filtering the examined transmission so that only packets with properties of interest to the network manager are captured or displayed. Facilities are usually provided to gather statistics, such as error rates, traffic between stations or groups of stations and so forth, as well as the packets themselves. Because of the need to capture and analyze large amounts of data, and the potential complexity of filtering, network monitors are expensive relative to other network components such as stations or bridges.

A serious limitation of prior-art network monitors is that the monitor must be connected physically to the network segment to be monitored. In a multi-port bridge where several network segments are connected by a bridge, it is only possible to examine one of the attached network segments at a time since the bridge isolates the physical media of the network segments. A further limitation is that the network monitor is not able to easily differentiate packets originating on the attached network segment and those originating on other network segments attached to the bridge and forwarded to the monitored network segment, especially if the packets have wrong addresses due to malfunction or sabotage. A router, moreover, replaces the source address of the packet by the router address, which makes it even more difficult for the network monitor to determine where the packet originated. In particular, it may be difficult or impossible for the monitor to isolate, for example, all the packets originating on a selected network segment.

One prior art approach to overcoming the limitation of connecting the monitor to only one network segment is the Distributed Sniffer™ from Network General. Each Sniffer is a network monitor coupled to a processing

element that can be controlled over the network. If several network segments attached to a bridge are to be monitored, then one Distributed Sniffer must be attached to each physical network segment. Operation of each Distributed Sniffer can be controlled over the network from a network-attached station using an upper level protocol such as TELNET. With this approach, one station located on any attached network segment can view results obtained from each Distributed Sniffer. The clear disadvantage of this approach is the cost of multiple Sniffers. A further shortcoming is a limited ability to correlate information gathered on different Sniffers. In particular, a Sniffer detecting a packet may be unable to determine the network segment on which the packet originated even if that network segment is connected to another Sniffer which has detected the packet, because the two Sniffers may be unable to determine whether the packet they have detected is the same packet or two different packets.

Additionally, each Distributed Sniffer must use some portion of the bandwidth of the monitored network to send information to the monitoring station, and thus the performance of the monitored network is affected.

SUMMARY OF THE INVENTION

According to the invention, monitoring of any or all network segments on a multi-port bridge or router may be carried out from a network segment on one port, referred to as a monitoring port. Packets of a selected network segment attached to a port designated as the monitored port are forwarded to their normal destination ports, if any, and also to the monitoring port. Monitored ports and monitoring ports may be specified in any number, thus allowing, for example, packet traffic from several ports to be simultaneously monitored at one port. To carry out monitoring, a network monitor of conventional design may

be connected to the monitoring port and will thus be able to view traffic just as if it were connected directly to a monitored port.

Port monitoring is enabled, disabled and specified via a supervisory access terminal attached to the bridge or router. Alternately, these supervisory functions are carried out from any network-attached terminal using well-known protocols. Using the supervisory access terminal, the network manager is able to define the type of traffic to be copied to the monitoring port. Several traffic types are allowed, for example, monitoring of all packets incoming to a selected port, all packets forwarded to a selected port or all packets generated within the bridge or router and then transmitted on a selected port. In particular, the packets originating on a selected network segment can be isolated for viewing on the network monitor. Further, the monitoring of traffic forwarded between selected pairs of ports is allowed.

Forwarding of a packet from a monitored port to a monitoring port does not require the packet to be copied from one place to another in the bridge's internal buffer memory. Instead, an indirect scheme is specified, that allows a packet to be sent to one or more destination ports without moving the packet. Internal data structures are defined to support efficient packet forwarding and to define the ports to which a packet should be forwarded under various circumstances. The data structures are intended to promote efficient forwarding and also to support simple and regular modification when a port monitoring command is issued from the supervisory access terminal.

Efficiency is also promoted through the use of a Bridging Cache that stores recent forwarding decisions for possible use in the near future.

It is therefore an object of this invention to allow a port monitoring device located on one port to monitor

traffic on any other port or ports of the bridge or router.

A further object is to allow selection of the type of packet traffic to be monitored.

It is another object of the invention to controllably restrict monitoring to those packets forwarded from one selected port to another selected port.

Another object of the invention is to "transmit" a single packet to multiple ports in an efficient manner and without the need to make multiple copies of the packet itself.

Yet another object of the invention is to promote an efficient way to carry out the forwarding computations.

It is also an object of the invention to improve the performance of the forwarding computation by caching recent forwarding results in anticipation that they will be used in the near future.

Other objects and features of the invention are described below.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other objects, aspects and advantages of the invention will be better understood from the following detailed description of the preferred embodiment of the invention with reference to the accompanying drawings, in which:

Figure 1 illustrates an example multi-port bridge with six attached network segments;

Figure 2 depicts the format of a packet in conformance with the Ethernet standard;

Figure 3 sets out two formats of packet destination address;

Figure 4 exhibits a Bridging Table related to the example system;

Figure 5 shows the evaluation of a Custom Filtering Rule;

Figure 6 is a block diagram of the example bridge;

Figure 7 depicts shared memory data structures related to packet reception and transmission;

Figure 8 illustrates the format of a Packet Descriptor;

Figure 9 illustrates the format of the XMASK;

Figures 10A and 10B illustrate the reception of a packet and the transmission of a packet, respectively;

Figure 11 is a state diagram illustrating the sequencing of Packet Descriptor state;

Figure 12 illustrates the Forwarding Table for the example bridge;

Figure 13 illustrates the Broadcast/Multicast Table for the example bridge;

Figure 14 illustrates the Management Table for the example bridge;

Figure 15 depicts a Bridging Cache;

Figure 16 is a flowchart of the forwarding algorithm;

Figures 17A and 17B depict the Forwarding Table and Broadcast/Multicast Table, respectively, after modification to support monitoring of incoming packets;

Figures 18A and 18B depict the Forwarding Table and Broadcast/Multicast Table, respectively, after modification to support monitoring of forwarded packets;

Figure 19 illustrates the Management Table after modification to support monitoring of generated packets.

Figures 20A and 20B depict the Forwarding Table and Broadcast/Multicast Table, respectively, after modification to support port-pair monitoring.

DESCRIPTION OF PREFERRED EMBODIMENT

The purpose of the bridge to be described below is to connect together multiple packet-based segments of a network, allowing efficient communications between stations on each network segment and also between stations located on different network segments connected to the

bridge. It is also possible for stations on network segments not connected to a common bridge to communicate, provided that there is at least one segment-to-segment path between the stations.

The example provided here is of a bridge, however, the operation is similar for routers, and the extension to routers will be clear to those skilled in the art.

In some embodiments, network segments attached to the bridge will employ a packet-based communication protocol based on either Ethernet or FDDI. Other packet-based protocols are possible. The details of Ethernet and FDDI protocols are well known and are documented in standards, particularly in IEEE Standard 802.3 for Ethernet and ANSI Standard X3T9.5 for FDDI. The following review of packet communications is intended to establish a terminology for further exposition of the preferred embodiment. The Ethernet scheme will be used as an example.

Figure 1 illustrates an example of a bridge with the port monitoring feature. In this example, the bridge **1** provides bridging services to six attached network segments **2.0** through **2.5** via ports **3.0** through **3.5** numbered 0 through 5. Item **2.0** illustrates a typical Ethernet configuration based on "10Base5" technology or "10Base2" technology in which the attached stations **4** are connected via a coaxial cable **5** of the appropriate type. Such a cable would be terminated electrically via terminator **6**. An alternative arrangement making use of "10BaseT" technology is shown for Port **5**. In this instance, each station is connected via a twisted pair of wires **7** to a unique connection **8** on the port.

Each station illustrated has been given a unique name consisting of a letter followed by a port number. This naming is arbitrary and is used only to simplify discussion in order to illustrate the operation of the invention.

Figure 1 also shows the attachment of a monitoring

device **9** to the monitoring port **10**. In the example system and in the discussion to follow, the monitoring port will be Port **4**. In some embodiments, the monitoring device **9** will be the only station on the network segment attached to the monitoring port **10**. A supervisory terminal **12** may also be attached to the bridge to provide control of the bridge in general and of the port-monitoring feature in particular. In the example system, this attachment is made via a supervisory port **11**, which is independent of the other ports illustrated and is only used to provide access to the bridge. It is possible, through the appropriate protocol, to provide access to supervisory terminal services at any of the connected stations **4**. In the example system, any or all of the ports **3** may be monitored ports.

In order to simplify discussion, it will be assumed that all ports (excepting the supervisory port **11**) in the example bridge **1** employ the Ethernet protocol. Under this protocol, stations **4** communicate by sending and receiving packets of information. Figure 2 illustrates the logical composition of a single packet **13**. The packet itself consists of a variable number of octets, or 8 bit data units, and is divided into fields of an integral number of octets as shown. The nomenclature and purpose of the fields is as follows:

Preamble **14** - A unique pattern used to synchronize the reception of packets

Destination Address **15** - A pattern that specifies the address of the station or stations **4** to receive the packet

Source Address **16** - A unique pattern specifying the address of the station **4** originating the transmission

Data **17** - The data to be transferred from the source station **4** to the destination station **4**

FCS **18** - A check sequence over packet (excluding

the preamble field) that is used by the destination stations to assess the validity of the received packet

Figure 3 illustrates the formation of the destination address **15** referred to also as DA. For purposes of illustration, two forms of DA may be used. One is the non-broadcast form **19** and the other is the broadcast form **20**. A DA **15** consists of 6 octets, or 48 bits, and one of these bits, the Broadcast/Multicast flag **21**, is used to differentiate between the two DA forms. When the Broadcast/Multicast flag is zero, the destination address consists of two components: a vendor code **22** and a device code **23**. These codes are assigned by a central authority so that each station has a unique station address. The station address is physically associated with the station and is used to identify it, no matter where it may be located on a network, either on a single-segment network or in a larger network composed of multiple segments.

In the case where the Broadcast/Multicast flag **21** is set to one, the DA field **15** is interpreted differently. If the remaining bits of the DA (the Broadcast/Multicast address **24**) are all ones, then the destination address is considered to designate all stations in the network, including stations on other segments connected to the bridge **1**. In the case where the Broadcast/Multicast flag **21** is one, but the remaining bits of the DA **15** are not all ones, a multicast packet is indicated. The remaining bits then signify a subset of stations in the network that are destinations. Such stations may be attached to any one or different segments. The identification protocol is application dependent and will not be further specified here.

The source address field **16**, also referred to as SA, identifies the source station using an addressing scheme as discussed for the DA **15**. The SA field does not make use of the Broadcast/Multicast flag, and so the contents

of the source address field always consist of the vendor code **22** and device number **23** only and thus uniquely identify the station originating the packet.

Within a single physical network segment **2**, such as that composed of stations A0, B0, and C0 of Figure 1, the operation of the packet protocol is straightforward. Stations transmit packets **13** in which the SA **16** contains their unique station address and in which the DA **15** contains the address of the station they wish to communicate with. Alternately, they can form a DA **15** so that it has broadcast address format **20** and the packet **13** will be received by all stations attached to the segment.

Each station attached to the segment listens to all transmissions on that segment and checks the DA of each packet. A packet is intended for a station's address if a non-broadcast DA matches its station address exactly or a Broadcast/Multicast DA is received. In the case of a Broadcast/Multicast DA **20**, the station will receive the packet if the Broadcast/Multicast address **24** matches according to application-specific rules.

BRIDGE OPERATION

The purpose of the bridge **1** is to allow stations on different attached network segments to communicate with each other. There are several advantages to using a bridge rather than simply forming one large common network electronically. By use of a bridge, network segments can be smaller physically (i.e., each segment can contain fewer station) and, therefore, each segment's electrical limits can be more easily met. From a performance standpoint, the transmission capacity of a segment is limited, and therefore the rate at which messages can be transferred between stations on a segment is limited. By subdividing a large segment into a collection of smaller segments connected by a bridge, the overall usage of a connected segment will be reduced on average. In the

illustrated example (Figure 1), for instance, stations on Port 2, such as A2 and C2, may communicate at full segment speed simultaneously while stations on another port, say Port 3, also use the full capacity of their attached segment.

The bridge **1** comes into play when a station on one segment, such as A0, must communicate with a station (or stations) on another segment, say C3. In this case, the bridge must pass packets for the two communicating stations between appropriate ports, in this case between Port 0 and Port 3. Because a station might be portable and thus might move from one segment to another, it is necessary for the bridge to implement an adaptive algorithm. One such prior-art algorithm is described in U.S. Patent 4,597,078, entitled *"Bridge Circuit for Interconnecting Networks."* Bridges constructed according to this algorithm are referred to as "learning bridges." The following brief discussion of learning bridge operation is given here, since this is the preferred mode of bridge operation to which the invention applies.

The key to learning bridge operation is that each station **4** has a unique address and that each packet **13** always contains the unique address of the originating station in the SA field **16**. In operation, the bridge examines and evaluates all packet transmissions on its attached ports **3**. Using information derived from this process, the bridge builds a Bridging Table **25**, as illustrated in Figure 4. Each Bridging Table Entry **26** consists of a Station Address field **27** and corresponding Port Number **28**. There is one Bridging Table Entry **26** for each station currently known to the bridge. In the Bridging Table Entry **26** the Port Number **28** indicates the port to which the corresponding station is attached. Figure 4 illustrates a Bridging Table corresponding to the example bridge and network configuration shown in Figure 1. In the illustrated case, all bridge-attached station

addresses are present in the Bridging Table **25**. Because networks have a dynamic character, it is not necessarily the case that all station address/port number pairs will be in the Bridging Table **25** at all times.

In a learning bridge, the Bridging Table **25** is built dynamically by the bridge, as discussed later. Ignoring for now the port monitor feature, the Bridging Table is used to forward received packets to their destinations as follows:

1. If the destination address field **15** of a received packet has the Broadcast/Multicast flag **21** set to one, then the packet is forwarded to all attached ports, except the port on which it was received.

2. If the destination address field **15** of a received packet has the Broadcast/Multicast flag **21** set to zero, then the DA field **15** contains a unique station address. The Bridging Table **25** is accessed using the DA field **15** of the received packet. If the Bridging Table **25** contains an entry with a Station Address field **27** matching the DA field **15** of the received packet, then the corresponding Port Number field **28** is retrieved. There are two cases to consider. If the retrieved port number **28** is identical to the port number on which the packet was received, then the packet is destined for the same network segment as the sending station. In this case, no action is taken as the transmission has already occurred on the proper segment. The alternative case is where the retrieved port number **28** does not match the port number on which the packet was received. In this case, the packet is forwarded to the port number indicated by the retrieved Bridging Table Entry **26**.

3. If during the process outlined in 2 directly above, the destination address field **15** of

the received packet does not match the Station Address field **27** of any Bridging Table Entry **26**, then the packet is forwarded to all attached ports, except for the port on which it was received. This ensures that the destination station, if present on any bridge-attached segment, will receive the packet.

In a learning bridge, the Bridging Table **25** is built dynamically, as packets are received. The bridge examines the source address field **16** of each packet received on each port. If the station address in the source address field **16** of a received packet matches the Station Address field **27** of an entry in the Bridging Table **25** and the port number on which the packet was received matches the port number field **28** of that entry, then the Bridging Table is not modified. However, if the SA **16** of a received packet matches a Station Address field **27** of a Bridging Table Entry **26**, but the port number on which the packet was received is not equal to the corresponding Port Number field **28** for that entry, then the Port Number field **28** is written with the port number on which the packet was received. Other actions, such as flushing the Bridging Cache **83** may also be required. However, if the source address **16** of the received packet does not match the Station Address field **27** of any Bridging Table entry **26**, then a new entry is added to the Bridging Table **25**. This entry consists of a Station Address field **27** containing the SA of the received packet and a corresponding Port Number field **28** containing the port number of the port on which the packet was received.

When the bridge is initialized, the Bridging Table **25** is empty. As packets on the attached network segments are examined, Bridging Table Entries **26** are formed and added to the Bridging Table **25**. By this process, the bridge "learns" the correspondence between the attached stations and the port to which they are attached. To accommodate for the fact that networks change and stations may be

added, removed or moved from one segment to another, the learning bridge incorporates an aging algorithm to periodically remove Bridging Table Entries **26** that have not been used for a period of time.

It is also possible for a network administrator to configure "permanent entries" in the Bridging Table. This avoids the need for the bridge to learn such entries, and can also be used to enhance network security. For example, the bridge could be configured not to forward packets to any DA on a particular port unless the Bridging Table contains a permanent entry for that DA, matching that port.

A further complication of bridge operation is that bridge **1** is typically part of a large network consisting of many bridges and their attached segments. The topology of the network might include loops in which there is more than one network path between two bridges. This may be unintentional or intentional, for example where redundancy is required in the network. In the case of broadcast packets or when a received packet has a DA **15** field for which no matching Bridging Table Entry **26** exists, the packet is forwarded to all ports. If network loops are present, this forwarding activity can lead to infinite duplication and propagation of a packet. To prevent this, the learning bridge implements an algorithm, referred to as a "spanning-tree algorithm", that limits the ports to which packets of the type discussed above can be forwarded. This algorithm is well defined by IEEE Standard 802.1d. Operation of the spanning-tree algorithm requires that the bridge **1** form an internal map of the network to which it is attached. This is done by communicating periodically with other bridges attached to the segments that are attached to the bridge **1**. Thus, there are instances in which the bridge itself may generate packets for transmission even though it has not received any specific packets instructing it to do so.

CUSTOM FILTERING OF PACKETS

In the forwarding operation discussed above, the bridge makes forwarding decisions based only on the DA field **15** of a packet **13**. However, more useful bridge operation can be had by further qualifying the forwarding decision based on specific contents of each packet. Under this additional regime, the forwarding of certain packets may be suppressed (that is, they are filtered out) if conditions based on packet contents are met. These conditions are referred to here as custom filtering rules (CFRs) and are implemented through the use of templates **29** as shown in Figure 5.

A template **29** consists of three components, an offset **30**, a 32-bit mask **31**, and a 32-bit comparator **32**. The template defines a test to be applied to a packet according to the following algorithm. First, the offset **30** is used to identify the start of a four-octet field, W, **33** of the packet. Offset **30** is expressed in octets from the start of the destination field **15**. The identified field, W, **30** is then logically ANDed bit for bit with the 32-bit mask **31**. The 32-bit result **34** is then compared at **35.1** logically (bit for bit) with the comparator **32** of the template yielding a logical result **35** which is *true* or *false*. If the result **35** of template evaluation is *true* (i.e., the result **34** equals the comparator **32**), then the packet is not forwarded (i.e., it is filtered). In the preferred embodiment, the filtering algorithm is implemented with software; however, a strictly hardware implementation or a mixed hardware/software implementation is also possible.

It is intended that the bridge **1** should provide for a plurality of templates and that facilities be provided to allow for multiple templates to be evaluated against a given packet and for the results of such evaluation **35** to be combined according to the well-known rules of Boolean logic. Thus, filtering of a packet can be based on quite

complex conditions. These complex conditions are referred to here as "custom filtering rules," or "CFRs." Through the proper construction of templates and CFRs, it is possible to filter out quite specific types of packets. For example all AppleTalk packets with an Appletalk source address of 15 (Hex) could be filtered by setting an offset of 16 (decimal), a mask of FF000000 (Hex), and a comparator of 15000000 (Hex). This might be used to prevent a particular station from communicating via Apple Talk protocol with selected other stations.

To further enhance the usefulness of CFRs, it is intended that the bridge allow for the association of CFRs with the port on which the packet is received, the SA **16** of the received packet, the DA **15** of the received packet, and the destination port (or ports) to which the packet is forwarded. Various combinations of such associations are also possible.

In the example bridge implementation, templates **29** and rules are defined through the use of the supervisory access terminal **12**.

SUMMARY OF BRIDGE OPERATIONS

From the discussion above, it will be seen that the bridge is able to handle several situations reflecting the various packet generating and forwarding situations. In summary, these include:

1. Forwarding of a single packet from one port to another.

2. Forwarding of multicast and broadcast packets to more than one port and possibly all ports.

3. Forwarding of management packets generated from within the bridge.

4. Suppression of packet forwarding to particular ports due, for example, to operation of the spanning-tree algorithm or for security purposes.

5. Filtering (suppression) of packet forwarding

due, for example, to the evaluation of custom filtering rules (CFRs).

ROUTER OPERATION

The discussion above has been related explicitly to bridges. However, the invention to be discussed also applies to routing. Packet routing involves receiving a packet on a port (i.e., from an attached network) and retransmitting it to another port based on information contained in the Data field **17**. The DA of a packet to be routed will be either the station address of the router or a broadcast/multicast address. The SA **16** is the station address of the station or router originating the packet. The router may be physically and/or logically incorporated in a bridge. (Devices which combined router and bridge functionality are known as "brouters".)

When a packet arrives at a router, the Data field **17** is parsed and examined. Specific protocols are defined for each type of packet to be routed and are indicated by sub-fields in the packet Data field **17**. One of the sub-fields may be a network address which is a logical, rather than a physical, address indicating the ultimate destination of the packet. To route the packet, the router modifies the DA **15** to point to the next link or hop in the route and substitutes its own address for SA **16**. Sub-fields of the Data field **17** may also be modified. In particular, there is usually a “hop count” indicating the maximum number of hops a packet may traverse before it is considered invalid or mis-routed. Other sub-fields of Data **17** may include control options, length, type, serial number, priority and so forth. These sub-fields are used to further specify the route.

CFRs may be applied to routed packets just as they are to bridged packets. It is also the case that some routed packets are consumed by the router or possibly generated internally for transmission to other routers.

Thus it will be seen that routed packets can generate packet forwarding situations similar to those arising for bridges, as discussed above under "Summary of Bridge Operations."

BRIDGE HARDWARE IMPLEMENTATION

Figure 6 illustrates the hardware of the example bridge **1** in block diagram form. In keeping with the example bridge discussed above, only 6 port controllers **37.0** through **37.5** are illustrated, although those skilled in the art of hardware system design will see that the design may be readily extended to additional ports **3**. Each port is based on the ILACC 32-bit Ethernet Controller, available from Advanced Micro Devices (AMD) of Sunnyvale, California. These controllers have the capability of sending and receiving packets directly to and from the shared memory **39** via the shared memory interface **38** without direct intervention of the bridge Main CPU **42** or I/O CPU **43**. This process will be discussed further below.

The bridge contains two processors whose primary function is to examine packets stored in the shared memory and make the appropriate changes to shared memory tables and data structures to allow forwarding to take place. The main CPU **42** is based on the MIPS R3001 25 MHz processor from Integrated Device Technology (IDT) of Santa Clara, California. Associated with the chip is a 256K Byte cache memory in which frequently referenced portions of the real-time packet forwarding code and control data are held. An attached Program Memory **41** contains up to 8 MBytes of additional storage for less time critical software and data, such as that related to the supervisory access function. A serial interface **45** is connected to the Main CPU to provide the Supervisory Access Port **11**. Also connected to the Main CPU **42** is a Floppy Disk **44** that provides a convenient means of updating the system

software and saving configuration information, such as permanent Bridging Table entries and CFRs, to be read at system startup.

A second processor, the I/O CPU **43**, is based on a MIPS R3051 33 MHz processor also available from IDT. The primary purpose of this processor is to supervise the sending and receiving of packets **13**, manage Packet Buffers in shared memory **39**, handle packet reception errors and similar activities. This processor supports an onboard cache **46**, which holds all of the I/O CPU code, thus providing very high performance.

Packets received from the ports and packets generated within the system to support management functions are stored in the shared memory **39**, which is based on a 1.5 Mbyte array of SRAMs. The structure of typical shared memory **39** is described in patent application "Methods and Apparatus for Data Transfer Between Source and Destination Modules," Serial Number 07/304,053, now U.S. patent No. 5,237,670. The configured array has an aggregate bandwidth of 400 Mbytes/second. Shared memory is made available to the port controllers **37**, the Main CPU **42**, and the I/O CPU **43** via the shared memory interface **38**. Each Port controller **37** is allocated 32 Kbytes of shared memory for received packets and 64 Kbytes of shared memory for transmitted packets.

PACKET DESCRIPTOR FORMAT

Packet forwarding is the process by which a received packet (or possibly one generated internally) is transmitted on one or more ports **3**. While the forwarding decisions are made primarily by the Main CPU, the port controllers **37** and the I/O CPU **43** also participate in the mechanics of forwarding.

Figure 7 shows shared memory **39** data structures involved in the reception, forwarding, and transmission of packets. Portions of these data structures can be

manipulated by the port controllers, Main CPU and I/O CPU. Packets being processed are stored in Packet Buffers **47** maintained in the Packet Buffer Pool **48**. Each Packet Buffer **47** is a contiguous shared memory area sufficient to hold an average sized Ethernet packet (of up to 256 octets). When longer packets must be handled, several Packet Buffers **47** are used.

Because even a minimum-size packet contains a considerable number of bytes (64), it is desirable to handle packets indirectly. This is done by means of a Packet Descriptor **49**, as shown in Figures 7 and 8. A Packet Descriptor **49** is a shared-memory data structure and has five components. The packet pointer **50** points to the actual packet data held in a Packet Buffer **47** in the Packet Buffer Pool **48**. As packets are processed, the Packet Descriptor **49** may be copied or moved. ("Move" means to copy and delete the original.) However, the packet itself is not moved or copied, it is only referred to via the packet pointer **50**. This indirect approach saves considerable shared-memory space and access bandwidth.

Flags **51** within the Packet Descriptor indicate various conditions related to packet status, such as the presence of errors and their causes. Packet processing is directed by the State field **52** of the Packet Descriptor. Details of packet processing and State field **52** manipulation will be discussed below. The Length field **53** indicates the length of the packet within the Packet Buffer **47**.

Within the Packet Descriptor **49** is the XMASK-Pointer **54** that points to an XMASK **55** indicating the destination port or ports (if any) to which the packet is to be transmitted. During forwarding, the Main CPU **42** fills in the XMASK-Pointer field based on the forwarding algorithm and conditions in effect at the time a packet is processed. Execution of the forwarding algorithm produces

a data quantity referred to as an XMASK **55** and illustrated in Figure 9.

XMASK **55** is simply a bit vector in which each bit indicates a port **3** to which the packet **13** is to be dispatched. Bit value "0" means, "Do not dispatch to the respective port", and bit value "1" means, "Dispatch to the respective port". If multiple bits are set, then the packet will be dispatched to each port indicated. If no bits are set, then the packet will not be dispatched (forwarded) to any port. For purposes of discussion and illustration, XMASK **55** will be represented in binary with the rightmost bit being the least significant bit and designating port 0. Table I shows some examples of XMASK values for the 6 port example system.

XMASK	**ACTION**
000000	Do Not Dispatch
000001	Dispatch to Port 0 only
010011	Dispatch to Ports 0,1 and 4
111111	Dispatch to All Ports

Table I: Examples of XMASK

A computed XMASK value **55** related to a packet **13** is held in the XMASK Pool **57**, a data structure in shared memory **39**. Within the Packet Descriptor **49**, the XMASK-Pointer field **54** will point to the computed XMASK **55** in the XMASK Pool **57**. This allows multiple Packet Descriptors **49** to point to the same XMASK value **55** and facilitates dispatching the same packet **13** to several ports, as would be required in a Broadcast/Multicast situation or when port monitoring is enabled.

For purposes of explaining the invention, some simplifications to the form of XMASK **55** have been made and certain optimizations will be evident to those skilled in

the art. For example, when XMASK **55** designates only one destination port, the port number itself may be held directly in the XMASK-Pointer **50** if a flag designating the alternate format is provided. This may be more efficient on some hardware systems.

PROCESSING OF PACKETS

Packet processing will be explained by way of example using Figures 10A and 10B, which illustrate changes to the shared memory data structure as packet processing progresses. Use will also be made of Figure 11 showing the sequence of processing steps. During packet processing, the actual Packet Buffer **47** is not moved or copied in shared memory **39**. Instead, the Packet Descriptor **49** associated with that packet buffer is moved from one shared memory data structure to the next and possibly copied and/or modified. In particular, the State field **52** of the Packet Descriptor **49** is modified according to the sequence outlined in Figure 11 where enclosed text, such as **64**, **65**, **66**, **67**, **68**, **69** and **70** represent states. What is shown in Figure 11 is the normal sequence of state processing where no errors have occurred.

In the example provided here, it is assumed that a packet will be received on Port 0 and sent to Ports 2 and 4. Initially, the configuration of memory will be as shown in Figure 10A. Associated with each port controller is a Receive Descriptor Ring (RDR) **72** and Transmit Descriptor Ring (TDR) **71** realized in shared memory **39**. Figures 10A and 10B only illustrate the RDR for Port 0 and the TDR for Ports 2 and 4. Receive and Transmit Descriptor Rings (**72** and **71**) are circular data structures of well known design and are of a fixed size designed to hold an integral number of Packet Descriptors **49**. Descriptor ring size is a design choice based on various system parameters of the particular implementation.

Initially, the RDR **72** will contain one or more Packet

Descriptors **49**, each with a State field **52** marked "Available for Reception" indicating that the associated Packet Buffers are available for the port controller **37** to fill with received packets. One Packet Descriptor in the RDR will be designated as to the next to be filled packet. Each "Available for Reception" Packet Descriptor **49** in the RDR will point to an empty Packet Buffer **47** in the Packet Buffer Pool **48** which is a data structure held in shared memory. With respect to the state diagram in Figure 11, the Packet Descriptor **49** is in the "Available for Reception" state **64**. When a packet arrives at Port 0, the Port 0 controller **37.0** will transfer the data received to the Packet Buffer **47**, as directed by the Packet Pointer field **50** of the Packet Descriptor **49**. In the preferred implementation, this process is under the control of the Port Controller **37** and occurs independently of other processes on other port controllers and processes on the Main CPU **42** and I/O CPU **43**. It will be recognized, however, that other approaches to providing independent processes are possible.

Once the Port 0 Controller has placed the received packet in the Packet Buffer **47**, it will update the Packet Descriptor **49** by supplying the proper Length field **53**, setting Flags **51** as required, and changing the State to "Received" **65** as shown in Figure 11. At this point, Port Controller 0 will access the next "Available for Reception" Packet Descriptor **49** in preparation for receiving a new packet.

Independently of the Port Controller operation, the I/O CPU **43** supports a process that polls each Port RDR **72** and inspects the Packet Descriptors **49**. When a Packet Descriptor **49** is found to be in the "Received" state **65**, the I/O CPU **43** will process the packet checking for packet errors and updating receive statistics (such as number of packets received on this port). Upon completion of this process, the State field **52** of the Packet Descriptor **49** is

marked as "Available for Forwarding" **66**.

The Main CPU **42**, working independently of the Port Controller **37** and the I/O CPU **43**, periodically polls all RDRs **72** to determine if any queued packets are to be forwarded. Based on the SA **16** and DA **15** fields of the Packet **13** and upon the port number of the RDR **72**, on which the packet is queued (RPORT), the Main CPU will carry out the Forwarding Algorithm as in Figure 16. The result of this process will be an XMASK value **55** designating the port or ports (possibly none) to which the packet **13** is to be forwarded. This XMASK **55** value will be placed in an available entry in the XMASK Pool **57** and the appropriate pointer to the entry will be entered into the XMASK-Pointer field **54** of the Packet Descriptor **49**. The State field **52** of the Packet Descriptor is then changed to "Forwarded" **67**.

Periodically, the I/O CPU **43** will scan the RDRs **72** to determine if any Packet Descriptors **49** are in a "Forwarded" state **67**. When such a Packet Descriptor **49** is found, it will be copied to each TDR **71** (if any) as indicated by the set bits in the associated XMASK value **55**. The State field **52** of each Packet Descriptor **49** copied to the TDR **71** is changed to "Available for Transmission" **68**. Each Packet Descriptor **49** copied to a TDR **71** will contain a Packet Pointer **50** pointing to the packet in the Packet Buffer Pool **48** and an XMASK-Pointer **54** pointing to the XMASK value **55** in the XMASK pool **57**. Once the I/O CPU **43** has copied a Packet Descriptor **49** to the appropriate TDRs **71**, the Packet Descriptor in RDR **72** is marked "Available for Reception" **64** and linked to an empty Packet Buffer **47** from the Packet Buffer Pool **48**. Figure 10B illustrates the situation after the example packet has been forwarded to the TDRs for ports 2 and 4.

Transmission of packets is carried out independently by the Port Controllers **37**. Each Port Controller **37** scans its associated TDR **71** and on encountering a Packet

Descriptor **49** with a State field **52** marked "Available for Transmission" **68** will begin transmitting the Packet **13** from Packet Buffer **47** to its associated port. Upon completion of the transmission, the State field **52** is marked "Transmitted" **69**. When a packet is sent to two or more ports, it may be transmitted at different times, since packet transmission on a particular port depends on the state of the TDR associated with that port and the traffic queued on that port.

Clean up of the TDR **71** is carried out by the I/O CPU **43**, which periodically scans all TDRs **71**. When a Packet Descriptor **49** with a State field **52** marked "Transmitted" **69** is found, the bit in the XMASK **55** designated by the XMASK Pointer **54** corresponding to the port under examination is reset. If the XMASK **55** is now cleared, there are no more outstanding Packet Descriptors **49** associated with the packet **13**; therefore, the Packet Buffer **47** is free and may be linked to a position on the Packet Buffer Free List **56** for later reuse. The Packet Descriptor **49** on the TDR **71** is marked as "Free" **70** making it available for reuse. Similarly, the XMASK **55** is made available for reuse in the XMASK Pool **57**.

Other issues related to packet processing, such as error handling and statistics gathering, have not been detailed here. The appropriate method of handling such issues is dependent upon the particular implementation and will be clear to those skilled in the art.

FORWARDING DATA STRUCTURES

Primary responsibility for forwarding packets resides in the Main CPU program. For purposes of illustrating the present invention, the data structures and operation of the forwarding algorithm will be discussed below. Only those features directly related to the port monitor feature will be explained. Initially, the discussion will be restricted to normal forwarding (i.e. when port

monitoring is disabled). It will be seen that the proposed data structures support rapid computation of the XMASK value **55**, which is used to direct packet forwarding. Once the normal case has been presented, the adjustments to the data structures necessary to provide port monitoring will be explained. These adjustments will also be seen to be particularly efficient in terms of implementation and execution.

Forwarding of a packet **13** is based on several inputs and produces, as an output, an XMASK value **55**. Required algorithmic inputs are DA **15** - the destination address of a received packet, RPORT - the port number on which the packet was received, SA **16** - the source address of the received packet, RSTATE - the state of the receiving port (RPORT **85**), NG -the network groups, and the current CFRs in effect.

RSTATE reflects the state of the receiving port. This is a port specific indicator (one per port) and indicates whether packets arriving at a port from its attached segment should be forwarded and whether packets from other ports or the packets generated within the bridge itself (management packets) may be forwarded to the port. RSTATE for a port varies slowly relative to the reception of packets and usually remains static for a long period of time. For example, RSTATE changes during the execution of the spanning-tree algorithm as ports are enabled and disabled to prevent logical loops.

NG, Network Groups, define which bridge-connected ports are allowed to communicate. NG values are defined by a network administrator using the supervisory terminal **12** or its network-based equivalent connection. Like RSTATE, NG values remain static for long periods of time relative to the transmission time of packets.

Because CFRs (Custom Filtering Rules) control packet transmission based on packet contents, possibly Data Field **17** contents, CFRs when specified will have a dynamic

effect on packet forwarding. That is, each packet arriving at a port (RPORT **85**) with the same SA **16** and DA **15** may be forwarded differently. Thus CFRs must be evaluated for every packet forwarded between ports and specific addresses (SA **16** and DA **15**) for which CFRs are currently defined. The discussion below initially assumes that CFRs are not in effect.

In operation, forwarding will depend on several data structures, the Bridging Table **25** (Figure **4**), the Forwarding Table **80** (Figure **12**), the Broadcast/Multicast Table **81** (Figure 13), Management Table **82** (Figure 14), and the Bridging Cache (Figure 15). The structure of the Bridging Table **25** has been discussed above.

Figure 12 illustrates the Forwarding Table **80**. This data structure is a two-dimensional array. One index of the array is RPORT **85**, the number of the port on which the packet to be forwarded was received. The other index is XPORT **86**, the number of the port on which the packet is to be sent based on the DA **15** field. XPORT **86** is determined by accessing the Bridging Table **25** with DA **15** and retrieving the corresponding Port Number field **28**. Entries in the Forwarding Table **80** are XMASK values **55** and reflect the current port-to-port connectivity of the bridge based on NG and RSTATE. For normal forwarding (port monitoring not in effect) XMASK **55** will either be null (all zeroes) or will indicate a single port. Figure 12 illustrates an example Forwarding Table **80** for a typical situation where all ports may communicate with each other. Null (all zeroes) XMASK values along the diagonal of the Forwarding Table indicate that if RPORT **85** is equal to XPORT **86** the packet should not be forwarded since the destination station is on the same port as the source station.

In the Forwarding Table **80** example of Figure 12, it is also assumed that Port 4 is isolated logically from all other ports. In the monitoring examples that follow, the

monitoring port **10** will be Port 4. In some embodiments, the Monitoring Port **10** is isolated logically so that only specifically identified monitored packets appear on the attached network segment. As a result "row 4" **59** (i.e., RPORT=4) and "column 4" **58** (i.e., XPORT=4) will contain null XMASK values **55**.

The Broadcast/Multicast Table **81** is illustrated in Figure 13. When a received packet indicates a Broadcast or Multicast address (that is when the Broadcast/Multicast flag **21** is set), the Broadcast/Multicast Table **81** is used in place of the Forwarding Table **80** to develop XMASK **55**. The Broadcast/Multicast Table **81** is a one dimensional array indexed by RPORT **85**. Each array entry is an XMASK value **55**. Figure 13 illustrates a Broadcast/Multicast Table **81** in which all ports are allowed to communicate with one another, except for Port 4, the monitoring port of the example. Therefore, each entry will have a 1 in each XMASK **55** bit position except for bit 4 (the monitoring port) and the bit corresponding to RPORT (thereby preventing broadcast to the source port).

Network Groups (NG) affect the contents of the Forwarding Table 80 and the Broadcast/Multicast Table 81. The examples in Figures 12 and 13 assume that all ports are allowed to communicate. If a network administrator has restricted communication by defining network groups, then some of the "1" entries in Figures 12 and 13 will be set to 0. For example, if ports 0 and 1 were defined as belonging to one network group, and ports 2, 3, 4, 5 were defined as belonging to another, then all of the Forwarding Table entries in the outlined regions 90, 92 in Figure 12 would be 000000. Similarly, the Broadcast/Multicast Table bits in the outlined regions 94, 96 in Figure 13 would also be zeros. Subsequent examples do not show Network Groups, but the port-monitoring operations described later take into account the possibility that Network Groups have been defined.

For packets generated within the bridge or router related to network management and router operation, Management Table **82** (Figure 14) is used. This table is a one dimensional array indexed by MPORT **78**, the port number on which the management related packet is to be sent. Figure 14 illustrates an example Management Table **82** in which each port is available for participation in management functions except for Port 4, the monitoring port **10**.

Although the Bridging Table **25** and the Forwarding Table **80** are sufficient for the XMASK **55** calculation, performance of the forwarding process can be improved significantly by the introduction of an additional data structure designated as the Bridging Cache **83** and shown for the preferred embodiment in Figure 15. Conceptually, the Bridging Cache **83** contains multiple logical entries in which specific RPORT **85**, SA **16** and DA **15** values are associated with an XMASK **55**. Since this association changes slowly, it is usually possible to bypass the normal forwarding calculation and retrieve the XMASK **55** value directly from the Bridging Cache **83**. Other factors, such as NG and RSTATE also change slowly and thus do not degrade the operation of the Bridging Cache **83** unduly.

When an XMASK value is calculated, the RPORT **85**, SA **16** and DA **15** value used in the calculation are combined into an entry and placed in the Bridging Cache **83**. When a new packet arrives for forwarding, the Bridging Cache **83** is accessed to determine if the RPORT **85**, SA **16** and DA **15** associated with the packet match the RPORT **85**, SA **16**, and DA **15** of a Bridging Cache entry. If a match is found, then the XMASK value **55** from the Bridging Cache **83** can be used. Otherwise, the full forwarding algorithm must be carried out.

In the preferred embodiment, the Bridging Cache is partitioned into separate sub-caches - one associated with each RPORT **85**. Since the maximum number of the receiving

ports is relatively small, this is a very efficient method of handling part of the cache look-up. The Bridging Cache is accessed with the 3-tuple <RPORT,SA,DA>. Based on RPORT **85**, the appropriate sub-cache associated **77** with the receive port is selected. Next the 96-bit value consisting of SA **16** concatenated with DA **15** is hashed using well-known techniques to produce a pointer to a Bridging Cache entry **79** in the selected sub-cache **77**. A comparison is then made between the input SA, DA values and the SA, DA values in the selected Bridging Cache entry **79**. If a match is obtained, the XMASK value **55** for that entry is retrieved. If no match occurs, the next Bridging Cache entry **79** is examined in like manner. This process continues until a match is found or a maximum number of attempts is made. Other approaches to accessing of the Bridging Cache **83** achieving the same result will be evident to those skilled in the art.

Use of the Bridging Cache **83** replaces the need to validate the received SA **16** in the Bridging Table **25**, to look-up XPORT **86** in the Bridging Table **25** and to use the Forwarding Table **80** to retrieve XMASK **55**. RPORT **85** and SA **16** are both used in the cache access so that changes to the port association of SA can be detected and accommodated as described next.

Bridging Cache entries **79** must be invalidated or flushed if they no longer reflect the outcome of the Bridging Algorithm. If, for example, the correspondence between SA **16** and RPORT **85** is found to be invalid, all Bridging Cache entries **79** with the corresponding SA **16** value in the RPORT sub-cache **77** must be cleared (the "flush" step in Figure 16). System level events may also cause a cache flush. For example, any change to the CFRs, the network groups NG, or the spanning-tree state may result in Bridging Cache entries **79** becoming invalid. In these cases, the offending Bridging Cache entries **79** must be removed or, if it is more efficient, all cache entries

may be invalidated. Commands issued from the Supervisory Access Terminal **12** (or its network equivalent) may also cause a cache flush.

In some embodiments, any port or address to which a CFR is applied is excluded from the Bridging Cache **83**. In other embodiments, Bridging Cache entries **79** include additional fields indicating the presence of a CFR and its point of application (DA, SA, RPORT). In some implementations this may allow CFR-related information to be accessed more quickly, depending on how data structures selected are realized.

It will be further recognized by those skilled in the art that alternatives to the Bridging Cache **83** data structures are possible while still preserving its performance-enhancing properties. Furthermore, it is also possible to associate the data structures discussed above, such as the Bridging Table **25**, the Bridging Cache **83**, with separate CPUs and memories, even though in the preferred embodiment they are implemented by code and data in the Main CPU **42** and Program Memory 41.

FORWARDING ALGORITHM

Packets that require forwarding may be incoming packets arriving at the bridge from its ports **3** or internally generated management packets. The forwarding algorithm discussed below operates in both cases and is also independent of whether port monitoring is enabled or disabled. To aid in illustrating the approach, a flow chart is provided in Figure 16. It is assumed that the forwarding algorithm will be entered with parameters DA **15**, SA **16**, RPORT **85** from incoming packets and with MPORT **78** for internally generated packets. Execution of the forwarding algorithm in the preferred embodiment is carried out on the Main CPU **42**.

Referring to Figure 16, it will be seen that first a packet source decision is made at **160.1**. Then, for

generated packets originating within the bridge, the XMASK value **55** is simply retrieved from the Management Table **82** at **16.2**.

For incoming packets, the SA **16** and DA **15** from the packet and the RPORT **85** value reflecting the port number on which the packet was received, are used at **160.3** to access the Bridging Cache **83**. If the 3-tuple <RPORT,SA,DA> is found in the Bridging Cache **83**, the XMASK value **55** is retrieved immediately and the bridging algorithm is complete. Control passes to dispatch step **160.4**. Alternatively, if the 3-tuple <RPORT,SA,DA> is not found, full processing of the packet addresses must take place. In some embodiments, the Bridging Cache **83** will never contain an XMASK entry **55** for a Broadcast/Multicast addresses or if a custom filter rule is applicable to DA, SA or their associated ports. This restriction avoids wasting space in the bridging cache, since custom filtering rules must make decisions on the packet data as well as the SA **16** and DA **15** and thus cannot have a valid, static XMASK **55** value in the Bridging Cache.

Full packet processing (i.e. when no matching cache entry is found), first involves a test of the DA **15** at **160.5** to determine if the Broadcast/Multicast flag **21** is set. If it is set then the XMASK value **55** is retrieved directly at **160.6** from the Broadcast/Multicast Table **81** using RPORT **85**.

If the Broadcast/Multicast bit is not set, then the next step, at **160.7**, is to access the Bridging Table **25** using SA **16** to determine if the source address and its associated RPORT value **85** are currently present and correct. If it is determined that the SA **16**, RPORT **85** relationship has changed or SA **16** is not present, then the Bridging Table **25** must be updated at **160.8** to reflect the new relationship. When this occurs, it is also necessary to search the Bridging Cache **83** and invalidate any entries with a Source Address field **16** equal to the SA **16** from

the received packet **13** (step **160.9**).

If the Bridging Table **25** access shows that SA **16** is present and has the correct RPORT value, then the Bridging Table **25** is re-accessed at **160.10** using DA **15** in an attempt to retrieve the XPORT value **15** corresponding to DA. In the event that an entry corresponding to DA **15** is not found, the RPORT value will be used to access the Broadcast/Multicast Table **81** to retrieve an XMASK **55**. This XMASK will indicate ports to which the packet will be directed in an attempt to place it on a network where DA is located.

When DA **15** is present in the Bridging Table **25**, the XPORT value **86** will be retrieved indicating the port where DA **15** is located. Using RPORT **85** and XPORT **86**, the Forwarding Table **80** is accessed at **160.11** and an XMASK **55** is retrieved.

After completion of the processing detailed here, an XMASK value **55** is available for use in dispatching. In cases where XMASK **55** is obtained from the Bridging Cache **83**, dispatching may be done directly. In all other cases, it is necessary to check for the presence of custom filtering rules (steps **160.12**, **160.13**). Flags indicating the presence of custom filtering rules are maintained in the Bridge Table **25** for SA **16** and DA **15** and in separate rule tables associated with each port. When indicated, the appropriate CFRs are evaluated and the XMASK **55** is modified as required to produce a final value (step **160.14**). This process can be quite involved and may affect performance significantly. When the processed packet is incoming (not generated) with a single station DA (not Broadcast or Multicast) and no CFRs are to be applied, the Bridging Cache **83** is updated at **160.15** from <RPORT,SA,DA> to reflect the new XMASK value **55**.

In the preferred embodiment, packets with Multicast/Broadcast addresses are not placed in the Bridging Cache **83**. There is nothing to prevent this from

being done; however such packets are a relatively small part of the total packet traffic. Therefore, the Bridging Cache **83** is better used if entries are devoted exclusively to single address DAs **15**. In situations with different traffic profiles from the preferred embodiment, it may be desirable to include multicast and broadcast addresses in the Bridging Cache **83**.

DESCRIPTION OF PORT MONITORING FEATURE

Port monitoring is a process by which packets arriving at the bridge or generated internally may be copied to one or more monitoring ports **10** (Figure 1). A monitoring device **9** attached to the monitoring port **10** is then able to provide analysis of the monitored packets. In the preferred embodiment, the monitoring device **9** would be, for example, a Sniffer™ from Network General or a LANalyzer™ from Novell. These devices analyze packet traffic on a network and provide various diagnostic information enabling the network manager to locate problems, evaluate performance, and determine appropriate adjustments to network parameters.

Port monitoring is controlled from the supervisory access terminal **12**. Using this terminal, the network manager may identify monitored ports **3** and monitoring ports **10**. When port monitoring is enabled, packets associated with the monitored ports **3** will be forwarded to monitoring ports **10**. In the preferred implementation, these packets are not actually copied, but the packet processing protocol described above is used in which only the Packet Descriptors **49** are copied.

Port monitoring is controlled by the Supervisory Access Terminal **12** using a simple command-line language. Table II illustrates the syntax of the commands. For each command, the prefix "pm" indicates that this is a port-monitoring command. There are three basic commands: "view", "viewpair" and "close". The first three commands

shown in Table II are of the "view" type as identified by the command word "view". These commands designate a <*monitored-port-number*> and <*monitoring-port-number*>. There is also a field to designate the type of monitoring desired, either "incoming", "forwarded" or "generated". Incoming packets are those arriving at a designated monitored port **3**. Forwarded packets are all packets forwarded to the designated monitored port **3** from any other port. Generated packets are those generated internally by the bridge and forwarded to the monitored port **3**. When the view command is given, all packets of the designated type will be "copied" from the port designated by <*monitored-port-number*> to the port designated by <*monitoring-port-number*>, in addition to their normal dispatching.

A "viewpair" command specifies a pair of ports **3** and a monitoring port **10**. Packets received on the port designated by the <*source-monitored-port-number*> and forwarded to the port designated by <*destination-monitored-port-number*> will be "copied" to the port designated by <*monitoring-port-number*>.

To terminate port monitoring, the "close" command is issued.

It is intended that the effect of individual commands be cumulative, that is, each processed command (except "close") will enable additional port monitoring. The effects of any commands issued since the previous "close" command will continue unchanged. Thus, through repeated application of the commands above, several ports may be designated as monitored ports, several ports may be designated as monitoring ports or various combinations thereof.

For illustrative purposes, a simple command language has been specified. It will be recognized that the command syntax outlined above could be enhanced using well-known techniques to provide a compound type of

command allowing several monitored ports, monitoring ports, and packet forwarding situations to be specified in one command line or through other types of user interfaces.

pm view incoming <*monitored-port number*> on <monitoring-port number>

pm view forwarded <*monitored-port number*> on <*monitoring-port number*>

pm view generated <*monitored-port number*> on <*monitoring-port number*>

pm viewpair <*source-monitored-port-number*>, <*destination-monitored-port-number*> on <*monitoring-port-number*>

pm close

Table II: Port Monitoring Command Syntax

IMPLEMENTATION OF PORT-MONITORING COMMANDS

Up to this point, the bridge **1**, its implementation and operation, has been illustrated only for normal operation, where port monitoring is disabled. Based on commands issued from the supervisory access terminal **12**, numerous aspects of port monitoring may be enabled. For the preferred implementation, port monitoring involves modifying the data structures discussed previously to indicate the monitored **3** and monitoring ports **10**. Modification will be illustrated for each of the monitoring situations: forwarded, incoming, generated, and port pairs.

To illustrate the effects of various port monitoring commands on the forwarding data structures, examples will be provided based on the use of Port 4 as the designated monitoring port **10**. For single-port monitoring, port 2 will be used, and for port-pair monitoring, port 2 will be the source-monitored-port and port 3 will be the destination monitored port.

For all the examples, the assumption has been made that the monitoring port, Port 4 is used only for

monitoring. Therefore, packets will only be forwarded to Port 4 due to the enabling of the port-monitor function. This is the preferred mode of operation for the bridge when port monitoring is enabled, since other stations on the monitoring port may be unable to properly interpret packet traffic arising from the port-monitoring function.

Monitoring of Incoming Packets

If incoming packets on a port are to be monitored, then all packets received at the designated monitored port must be copied to the monitoring port. Packets are copied to the monitoring port even if they are not to be sent to any other port (i.e. they are consumed by the bridge). When monitoring of incoming packets is required, the Forwarding Table **80** and the Broadcast/Multicast Table **81** are modified. The Management Table **82** is not modified, since it affects only generated packets.

To enable monitoring of incoming packets on <*monitored-port-number*>, each entry in the Forwarding Table **80** where RPORT **85** is equal to <*monitored-port-number*> is modified. For each such entry, the XMASK bit corresponding to <*monitoring-port-number*> is set. Figure 17A shows the results of executing the command "pm view 2 on 4" on the example Forwarding Table of Figure 12. Since port 2 is to be monitored on Port 4, each XMASK entry **55** in "row 2" **60** will have bit 4 set.

A similar modification must be made to the Broadcast/Multicast Table **81**. For the XMASK entry **55** where RPORT **85** is equal to <*monitored-port-number*> the XMASK bit corresponding to <*monitoring-port-number*> is set. Figure 17B illustrates the results of executing "pm view 2 on 4" on the example Broadcast/Multitask table **81** of Figure 13. Due to command execution, the entry **61** for RPORT = 2 has bit 4 corresponding to the monitoring port set. For the other entries, bit 4 is unchanged and remains cleared since Port 4 is isolated to support port

monitoring in the preferred manner.

No modifications are made to the Management Table **82** to support the monitoring of incoming packets since XMASK values **55** in the table apply only to packets generated by the bridge.

Monitoring of Forwarded Packets

In the case where forwarded packets are to be monitored, it is necessary to modify XMASK entries **55** in the Forwarding Table **80** and Broadcast/Multicast Table **81** so that each packet forwarded to a designated <*monitored-port-number*> is also "copied" to the <*monitoring-port-number*>. No changes are made to the Management Table **82**.

To accommodate monitoring of packets forwarded to <*monitored-port-number*>, the bit corresponding to <*monitoring-port-number*> must be set in the XMASK of each entry in the Forwarding Table **80** where XPORT is equal to <*monitored port number*> except for the entry where RPORT is equal to <*monitored-port-number*>. Figure 18A shows the result of executing the command "pm view forwarded 2 on 4" on the example Forwarding Table **80** of Figure 12. The modified entries are the "column 2" **73** and indicate that packets forwarded to port 2 should also be forwarded to Port 4, the monitoring port. The entry where RPORT=XPORT=2 has a null XMASK (000000) since packets received on port 2 should not be forwarded to that port.

Broadcast/Multicast packets can also be forwarded to the monitored port **3**, thus it is necessary to modify the Broadcast/Multicast Table **81**. Each XMASK entry in the Broadcast/Multicast Table **81** is modified by ORing the bit corresponding to <*monitored-port-number*> with the bit corresponding to <*monitoring-port-number*> and placing the result in the bit corresponding to <*monitoring-port-number*>. Figure 18B shows the results of modifying the Broadcast/Multicast Table of Figure 13 according to the command above. The result is that "bit column" 2 **62** is

ORed with "bit column" 4 **63**, and the result is returned to bit column 4 **63** indicating that each Broadcast/Multicast packet from an RPORT that is forwarded to port 2 should also be forwarded to Port 4.

Monitoring of Generated Packets

Monitoring of generated packets involves modifying only the Management Table **82**. The Forwarding Table **80** and the Broadcast/Multicast Table **81** remain unchanged since they have no effect on the forwarding of generated packets originating within the bridge itself.

To enable monitoring of generated packets, each XMASK entry **55** in the Management Table **82** is modified so that the bit corresponding to <*monitored-port-number*> is ORed with the bit corresponding to <*monitoring-port-number*>, and the result is placed in the bit corresponding to <*monitoring-port-number*>.

Figure 19 illustrates the result of the command "pm view generated 2 on 4" as applied to the example Management Table of Figure 14. "Bit column" 2 **75** corresponding to the monitored port 2 has been ORed with "bit column" 4 **76** representing the monitoring Port 4, and the result is returned to bit column 4 **76**.

Monitoring of Port Pairs

When port-pair monitoring is enabled, packets originating on a source monitored port **3** and forwarded to a destination monitored port **3** will be copied also to the monitoring port **10**. To support this option, the Forwarding Table **80** and Broadcast/Multicast table **81** must be modified but the Management Table **82** is unchanged.

The XMASK entry **55** in the Forwarding Table **80** designated by RPORT= <*source-monitored-port number*> and XPORT=<*destination-monitored-port-number*> is modified by setting the XMASK bit corresponding to <*monitoring-port-number*>. Figure 20A shows the results of applying the

command "pm view pair 2 3 on 4" to the example Forwarding Table **80** of Figure 12. The modified entry **84** is highlighted.

In the Broadcast/Multicast Table **81**, the entry corresponding to RPORT=<*source-monitored-port number*> is modified by ORing the XMASK bit corresponding to <*destination-monitored-port-number*> with the bit corresponding to <*monitoring-port-number*> and placing the result in the bit corresponding to <*monitoring-port-number*>. Figure 20B shows the result of applying the above command to the example Broadcast/Multicast Table of Figure 13. Only the RPORT=2 entry **61** corresponding to the source monitored port is modified by ORing XMASK bit 3 (corresponding to <*destination-monitored-port-number*>) with bit 4 (corresponding to <*monitoring-port-number*>) and placing the result in bit 4. No change to the Management Table **82** is required to enable monitoring of a port pair.

Close Command

The effects of port monitoring are cumulative. When a "pm close" command occurs, the Forwarding Table **80**, Broadcast/Multicast Table **83** and Management Table **82** are simply restored to their original state before the application of any "pm view" or "pm viewpair" command.

Other Issues Related to Port Monitoring

Port Monitoring works naturally with the Bridging Cache **83**. XMASK values obtained from the Forwarding Table **80** are placed in the Bridging Cache **83** provided no CFRs are in effect as would be the case in normal processing. Operation of the Bridging Cache **83** is unaffected by port monitoring.

CFRs may be applied to the monitoring port **10**. However, in the preferred embodiment this was not allowed so as to improve efficiency.

Because the application of monitoring commands may change XMASK values **55**, it is important to flush the Bridging Cache **83** whenever a monitoring command is given.

In some embodiments, packets with errors and those that are too large or too small are not "copied" to monitoring port **10**. This could be done if it was desirable in a particular implementation.

The uncertainty as to the monitored packet's originating network segment is reduced. Indeed, the bridge knows precisely on which port each incoming packet was received, even if the packet's SA is wrong due to malfunction or sabotage. Thus the packets received on precisely selected port or ports can be isolated and forwarded to the network monitor even if the packets have wrong source addresses. The bridge debugging is therefore facilitated. In particular, security problems become easier to solve. The uncertainty is reduced also in the router embodiments because the router also determines the packet's receiving port independently of the packet's SA.

In some embodiments, different network segments connected to the bridge use different protocols. The bridge translates packets from one protocol format to another as needed. In particular, each packet transmitted to the monitoring port **10** is translated, if needed, to the format of the segment attached to the monitoring port. The bridge's ability to translate packets allows freedom in selecting the network segment attached to the monitoring port. For example, in some embodiments, some non-monitoring port segments are FDDI segments, and the segment attached to the monitoring port is an Ethernet segment. Using the Ethernet segment allows reducing the network cost because Ethernet network monitors are typically less expensive than FDDI network monitors.

PORT MONITORING IN ROUTERS

In router implementations, many of the basic issues

related to port monitoring are also present. Packets are routed based on the contents of the Data Field **17**. Routing depends on data structures similar to those used in bridging. For instance, there may be a Routing Table for translating network addresses into ports and network destinations. There may also be Address Resolution Tables to translate router and host targets into actual Ethernet addresses, which are in turn used to update the DA **15** of the packet **13** to direct it to the next link or to the final destination. As in bridging, performance can be improved by caching recently calculated results. For example, the Network address, Ethernet address and port number may be cached together with an XMASK **55** value. Because the forwarding decision depends on many factors, such as router state, state of the next hop, and the state of the route it is not possible to compute the XMASK **55** in a static, direct manner as can be done for bridging. When monitoring is enabled, the XMASK **55** derived from the Routing Table and Address Resolution Table is modified algorithmically according to the monitoring currently enabled. This XMASK **55** is then cached for later reference in the Routing Cache.

When forwarding an incoming packet, a router normally modifies a portion of the packet header. For example, it replaces the SA and DA of the received packet with its own SA and the DA of the next hop, and it may update a hop count. When port monitoring is in effect, the packet forwarded on the monitoring port is the <u>modified</u> packet, not exactly the received packet.

In some embodiments, in order to forward exactly the received packet to the monitoring port, the router makes a copy of the received packet before modifying it. It will be apparent to those skilled in the art that it may not be necessary to copy the entire packet, only the modified part, if the Port Controllers **37** can "gather" multiple buffers into a single packet for transmission. In this

case, an extra buffer can be allocated for the copied and modified part of the packet, while the original buffer can be used to forward the packet to the monitoring port (or vice versa).

While the invention has been described in terms of a preferred implementation based on a specific bridge and network example, those skilled in the art will recognize that the invention can be practiced with modification and extension within the spirit and scope of the appended claims.

CLAIMS

1. An inter-network communication apparatus comprising:

a plurality of ports P for connecting the apparatus to a plurality of network segments;

a port MP for connecting the apparatus to a network monitor; and

means M1 for transmitting packets of information to one or more of the ports P wherein each packet of information includes information I1 for determining one or more ports P to which the packet of information is to be transmitted, wherein the means M1 can transmit a packet of information: (1) to one or more of the ports P determined based on the information I1 in the packet and, in addition, (2) to port MP.

2. The apparatus of Claim 1 further comprising said network segments and said network monitor.

3. The apparatus of Claim 1 wherein:

the means M1 comprises a store for storing one or more entries of the form (RPORT, SA, DA, XP) wherein:

RPORT identifies one of ports P;

SA is a source address;

DA is a destination address; and

XP identifies zero, one, or more than one of ports P and MP to which information which is received on port RPORT and which has a source address SA and a destination address DA is to be transmitted; and

said apparatus further comprises means M for searching said store, when information is received, for an entry whose RPORT identifies the port on which the information is received and whose SA and DA

correspond, respectively, to a source address and a destination address of the received information, wherein, if such an entry is found, means M determines destination ports for the received information from XP of the found entry.

4. The apparatus of Claim 3 wherein, for each entry, XP is a map in which, for each port, one or more bits specify whether information is to be transmitted to said port.

5. An apparatus for allowing a plurality of units to communicate with each other, said apparatus comprising:

one or more ports P for connection to said units;

a port MP for connecting a monitoring system to said apparatus; and

means for transmitting packets of information to said ports P and MP such that each packet of information includes information I1 for determining one or more ports to which the packet is to be transmitted, wherein said transmitting means can select a subset of packets of information and can transmit each packet of the selected subset to one or more ports determined based on the information I1 in the packet, and wherein said transmitting means can transmit each packet of the selected subset to said port MP whether or not the port MP is a port determined based on the information I1 in the packet.

6. The apparatus of Claim 5 wherein each unit comprises a network segment.

7. The apparatus of any one of Claims 1 through 6 wherein said transmitting means can transmit to port MP information incoming on one or more selected ports P

without transmitting to port MP all incoming and outgoing information on said selected ports.

8. The apparatus of any one of Claims 1 through 7 wherein said transmitting means can transmit to port MP information forwarded to one or more selected ports P without transmitting to port MP all incoming and outgoing information on said selected ports.

9. The apparatus of any one of Claims 1 through 8 wherein said transmitting means can transmit to port MP information generated by said apparatus for transmission to one or more selected ports P without transmitting to port MP all incoming and outgoing information on said selected ports.

10. The apparatus of any one of Claims 1 through 9 wherein said transmitting means can transmit to port MP information forwarded from a selected port P1 of ports P to a selected port P2 of ports P without transmitting to port MP all incoming and outgoing information on ports P1 and P2.

11. The apparatus of Claim 1 or 5 wherein said transmitting means comprises a store for storing for each pair (RPORT, XPORT) of ports P information identifying all those ports P and MP to which the apparatus is to transmit information having a source address corresponding to port RPORT and a destination address corresponding to port XPORT.

12. The apparatus of Claim 1 or 5 wherein said transmitting means comprises a store for storing for each port RPORT of ports P information identifying all those ports P and MP to which the apparatus is to transmit information having a source address corresponding to port

RPORT and a destination address specifying a broadcast or multicast transmission.

13. The apparatus of any one of Claims 1 through 12 wherein said transmitting means comprises means for applying one or more custom filtering rules to determine which information is to be transmitted to port MP.

14. An apparatus comprising:

a plurality of ports for connecting to said apparatus a plurality of network segments and one or more network monitors, wherein one or more of said ports can be designated as monitoring ports to be used for connecting to said apparatus one or more network monitors; and

means for transferring packets of information among said ports according to a bridging or routing algorithm and for transmitting according to said algorithm selected packets of information to one or more of said monitoring ports, wherein each packet of information includes information I1 for determining one or more ports to which the packet of information is to be transmitted and said means is responsive to a command to transmit the selected packets to one or more of said monitoring ports whether or not the information I1 in any selected packet determines any monitoring port as a port to which the selected packet is to be transmitted.

15. The apparatus of Claim 1, 5 or 14 wherein said apparatus is a bridge.

16. The apparatus of Claim 14 further comprising:

a store for specifying whether information incoming on a non-monitoring port is to be

transmitted to one or more of said monitoring ports; and

means for transmitting information in accordance with contents of said store.

17. The apparatus of Claim 14 further comprising:

a store for specifying whether information forwarded to a non-monitoring port is to be transmitted to one or more of said monitoring ports; and

means for transmitting information in accordance with contents of said store.

18. The apparatus of Claim 14 further comprising:

a store for specifying whether information generated by said apparatus and transmitted to a non-monitoring port is also to be transmitted to one or more of said monitoring ports; and

means for transmitting information in accordance with contents of said store.

19. The apparatus of Claim 14 further comprising:

a store for specifying whether information forwarded from one selected non-monitoring port to another selected non-monitoring port is to be transmitted to one or more of said monitoring ports; and

means for transmitting information in accordance with contents of said store.

20. A method for monitoring one or more ports of a communication apparatus interconnecting a plurality of network segments, said method comprising the steps of:

connecting to one or more ports MP of said ports one or more monitoring systems; and

selecting packets of information, each packet including information I1 for determining one or more ports to which the packet is to be transmitted, and transmitting by the apparatus selected packets of information to one or more ports MP whether or not the information I1 in any selected packet determines any port MP as a port to which the selected packet is to be transmitted.

21. The method of Claim 20 wherein the selected packets of information comprise information received on a selected port connected to a network segment.

22. The method of Claim 20 wherein the selected packets of information comprise information forwarded to a selected port connected to a network segment.

23. The method of Claim 20 wherein the selected packets of information comprise information generated by the apparatus and transmitted to a selected port connected to a network segment.

24. The method of Claim 20 wherein the selected packets of information comprise information forwarded from one selected port connected to a network segment to another selected port connected to a network segment.

25. The apparatus of Claim 1 wherein:

the means M1 comprises a store for storing one or more entries each of which comprises a triple (SA, DA, XP) wherein:

SA is a source address;

DA is a destination address; and

XP identifies zero, one, or more than one of ports P and MP to which a packet having a

source address SA and a destination address DA is to be transmitted; and

said apparatus further comprises means M for searching said store, when a packet of information is received, for an entry whose SA and DA correspond, respectively, to a source address and a destination address of the received packet, wherein, if such an entry is found, means M determines destination ports for the received information from XP of the found entry.

26. The apparatus of Claim 1 wherein the means M1 comprises:

a store for storing: (1) buffers for storing packets of information, (2) for each port P1 of ports P, a first data structure for containing one or more pointers to one or more buffers that store packets received on the port P1, and (3) for each port P2 of the ports P and MP, a second data structure for containing one or more pointers to one or more buffers that store packets to be transmitted on the port P2;

means M2 for transmitting on each port packets stored in buffers pointed to by pointers contained in the second data structure of the port; and

means for copying at least one pointer from the first data structure of a first port to the second data structures of one or more second ports to forward a packet received on the first port to the one or more second ports.

27. The apparatus of Claim 5 wherein said transmitting means comprises a store for storing for each port MPORT of ports P information identifying all those ports P and MP to which the apparatus is to transmit

packets generated by said apparatus and having the information I1 corresponding to port MPORT.

28. The apparatus of Claim 1 or 27 wherein the information I1 comprises a destination address.

29. The apparatus of Claim 1, 5 or 14 wherein the packets have a variable number of data units.

30. The method of Claim 20 further comprising the steps of:

storing packets of information in buffers; and

providing for each port P2 of said ports a data structure for containing one or more pointers to one or more buffers that store packets to be transmitted on the port P2,

wherein the step of selecting packets of information and transmitting the selected packets comprises the step of transmitting on each port P2 packets stored in buffers pointed to by pointers in the data structure of the port P2.

31. The method of Claim 30 further comprising the step of receiving a packet PC1 of information on one of said ports wherein the step of selecting packets and transmitting selected packets further comprises the steps of:

determining one or more ports to which the packet PC1 is to be transmitted; and

inserting a pointer to a buffer storing at least a portion of the packet PC1 into the data structure of each port on which the packet PC1 is to be transmitted.

32. The method of Claim 20 wherein the packets have a variable number of data units.

AMENDED CLAIMS

[received by the International Bureau on 02 December 1994 (02.12.94); original claims 1-32 cancelled; new claims 33-62 added; (8 pages)]

33. An apparatus for allowing a plurality of units to communicate with each other, the apparatus comprising:

a plurality of ports for connection to the units and to one or more monitoring systems; and

first means for transmitting packets of information to one or more of the ports, wherein each packet of information comprises forwarding information to be used in determining the packet destination;

wherein the first means comprises means for transmitting each of one or more packets: (1) to one or more ports determined from the packet destination if the destination includes a unit other than the apparatus; and, in addition, (2) to one or more monitoring ports, wherein each monitoring port is one of said ports and each monitoring port allows connection to a monitoring system.

34. The apparatus of Claim 33 wherein each monitoring port allows connection to a network segment accessible to a network monitor.

35. The apparatus of any one of the preceding claims wherein the first means allows substantially parallel transmission of a packet: (1) to one or more ports determined based on the packet destination and, in addition, (2) to one or more monitoring ports.

36. The apparatus of any one of the preceding claims further comprising second means for specifying to the first means which packets are to be transmitted to one or more monitoring ports, wherein the second means allows specifying such packets at any time during the operation of the first means.

37. The apparatus of any one of the preceding claims wherein each of the ports allows connection to a network segment.

38. The apparatus of any one of the preceding claims wherein the plurality of ports comprises:

one or more ports for connection to one or more network segments employing a first protocol format; and

one or more ports for connection to one or more network segments employing a second protocol format different from the first protocol format;

wherein the one or more monitoring ports include a first monitoring port for connection to a network segment employing the first protocol format; and

wherein the first means comprises means to translate packets from the second protocol format to the first protocol format to allow packets received from a network segment employing the second protocol format to be transmitted to the first monitoring port.

39. The apparatus of any one of the preceding claims wherein the first means comprises a store for storing one or more data structures that allow the first means to determine, using a packet's forwarding information, all the ports, if any, to which the packet is to be transmitted; and

wherein the apparatus further comprises means to modify the data structures in response to commands so as to define which packets should be transmitted to which monitoring ports.

40. The apparatus of Claim 39 wherein the commands include a command to transmit to a monitoring port packets incoming on a selected port.

41. The apparatus of Claim 39 or 40 wherein the commands include a command to transmit to a monitoring port packets forwarded to a selected port for transmission.

42. The apparatus of Claim 39, 40 or 41 further comprising means for generating packets,

wherein the commands include a command to transmit to a monitoring port packets generated by the generating means.

43. The apparatus of any one of Claims 39-42 wherein the commands include a command to transmit to a monitoring port packets incoming on a first selected port and forwarded to a second selected port for transmission.

44. The apparatus of any one of the preceding claims wherein the first means comprises means for applying one or more custom filtering rules to determine which packets are to be transmitted to a monitoring port.

45. The apparatus of any one of the preceding claims wherein the packets have a variable number of data units.

46. The apparatus of any one of the preceding claims wherein:

each packet's forwarding information comprises a source address and a destination address;

the first means comprises a store S1 for storing one or more entries of the form (RPORT, SA, DA, XP) wherein:

RPORT identifies one of the ports;

SA is a source address;

DA is a destination address; and

XP identifies zero, one, or more than one ports to which a packet which is received on port RPORT and which has a source address SA and a destination address DA is to be transmitted; and

the apparatus further comprises means M for searching the store S1, when a packet is received, for an entry whose RPORT identifies the port on which the packet is received and whose SA and DA correspond, respectively, to a source address and a destination address of the received packet, wherein, if such an entry is found, the means M determines from XP of the found entry those ports to which the received packet is to be transmitted.

47. The apparatus of any one of Claims 33-45 wherein:

each packet's forwarding information comprises a source address and a destination address;

the first means comprises a store S2 for storing one or more entries each of which comprises a triple (SA, DA, XP) wherein:

SA is a source address;

DA is a destination address; and

XP identifies zero, one, or more than one ports to which a packet having a source address SA and a destination address DA is to be transmitted; and

the apparatus further comprises means M for searching the store S2, when a packet is received, for an entry whose SA and DA correspond, respectively, to a source address and a destination address of the received packet, wherein, if such an entry is found, the means M determines from XP of the found entry those ports

to which the received packet is to be transmitted.

48. The apparatus of Claim 46 or 47 wherein, for each entry, XP is a map in which, for a port, one or more bits specify whether information is to be transmitted to said port.

49. The apparatus of any one of the preceding claims wherein the first means comprises:

a store for storing: (1) buffers for storing packets of information, (2) for each port P1 of one or more of the ports, a first data structure for containing one or more pointers to one or more buffers that store packets received on the port P1, and (3) for each port P2 of one or more of the ports, a second data structure for containing one or more pointers to one or more buffers that store packets to be transmitted on the port P2;

means M2 for transmitting, on each port having a second data structure, packets stored in buffers pointed to by pointers contained in the second data structure of the port; and

means for copying at least one pointer from the first data structure of a first port to the second data structures of one or more second ports to forward a packet received on the first port to the one or more second ports.

50. A method for monitoring a network comprising an apparatus interconnecting a plurality of network segments at least one of which comprises a network monitor, the method comprising:

(a) obtaining, from each packet received or generated by the apparatus, forwarding information to be used in determining the packet destination;

(b) if a packet destination includes a station other than the apparatus, then

transmitting the packet to one or more of the network segments in order to deliver the packet to the packet destination; and

(c) if a packet is to be delivered to a network monitor, then transmitting the packet to a network segment comprising the network monitor.

51. The method of Claim 50 wherein for at least one packet whose destination includes a station other than the apparatus and which is to be delivered to a network monitor, the steps (b) and (c) are performed substantially in parallel.

52. The method of Claim 50 or 51 wherein:

one or more of the network segments employ a first protocol format;

one or more of the network segments employ a second protocol format different from the first protocol format;

at least one network segment comprising a network monitor employs the first protocol format; and

the method further comprises translating one or more packets received on one or more network segments employing the second protocol format from the second protocol format to the first protocol format and transmitting such packets to a network segment which comprises a network monitor and employs the first protocol format.

53. The method of any one of Claims 50-52 further comprising:

storing in a store one or more data structures for determining, using a packet's forwarding information, all the network segments, if any, to which the packet is to be transmitted; and

modifying the data structures in response to a command so as to define which packets should be transmitted to which network segments comprising network monitors.

54. The method of Claim 53 wherein the command is a command to transmit to a network segment comprising a network monitor packets incoming from a selected network segment.

55. The method of Claim 53 wherein the command is a command to transmit to a network segment comprising a network monitor packets transmitted in step (b) to a selected network segment.

56. The method of Claim 53 further comprising generating packets by the apparatus,

wherein the command is a command to transmit to a network segment comprising a network monitor packets generated by the generating step.

57. The method of Claim 53 wherein the command is a command to transmit to a network segment comprising a network monitor packets received from a first selected network segment and transmitted in step (b) to a second selected network segment.

58. The method of any one of Claims 50-57 wherein the step (c) comprises applying one or more custom filtering rules to determine whether a packet is to be delivered to a network monitor.

59. The method of any one of Claims 50-58 wherein the packets have a variable number of data units.

60. The method of any one of Claims 50-59 further comprising the steps of:

storing packets of information in buffers; and

providing for each port P2 of said ports a data structure for containing one or more pointers to one or more buffers that store packets to be transmitted on the port P2,

wherein at least one of steps (b) and (c) comprises transmitting on each port P2 packets stored in buffers pointed to by pointers in the data structures of the port P2.

61. The method of Claim 60 wherein each of steps (b) and (c) comprises transmitting on each port P2 packets stored in buffers pointed to by pointers in the data structures of the port P2.

62. The method of Claim 60 or 61 further comprising:

receiving a packet PC1 on one of the ports;

determining one or more ports to which the packet PC1 is to be transmitted; and

inserting a pointer to a buffer storing at least a portion of the packet PC1 into the data structure of each port on which the packet PC1 is to be transmitted.

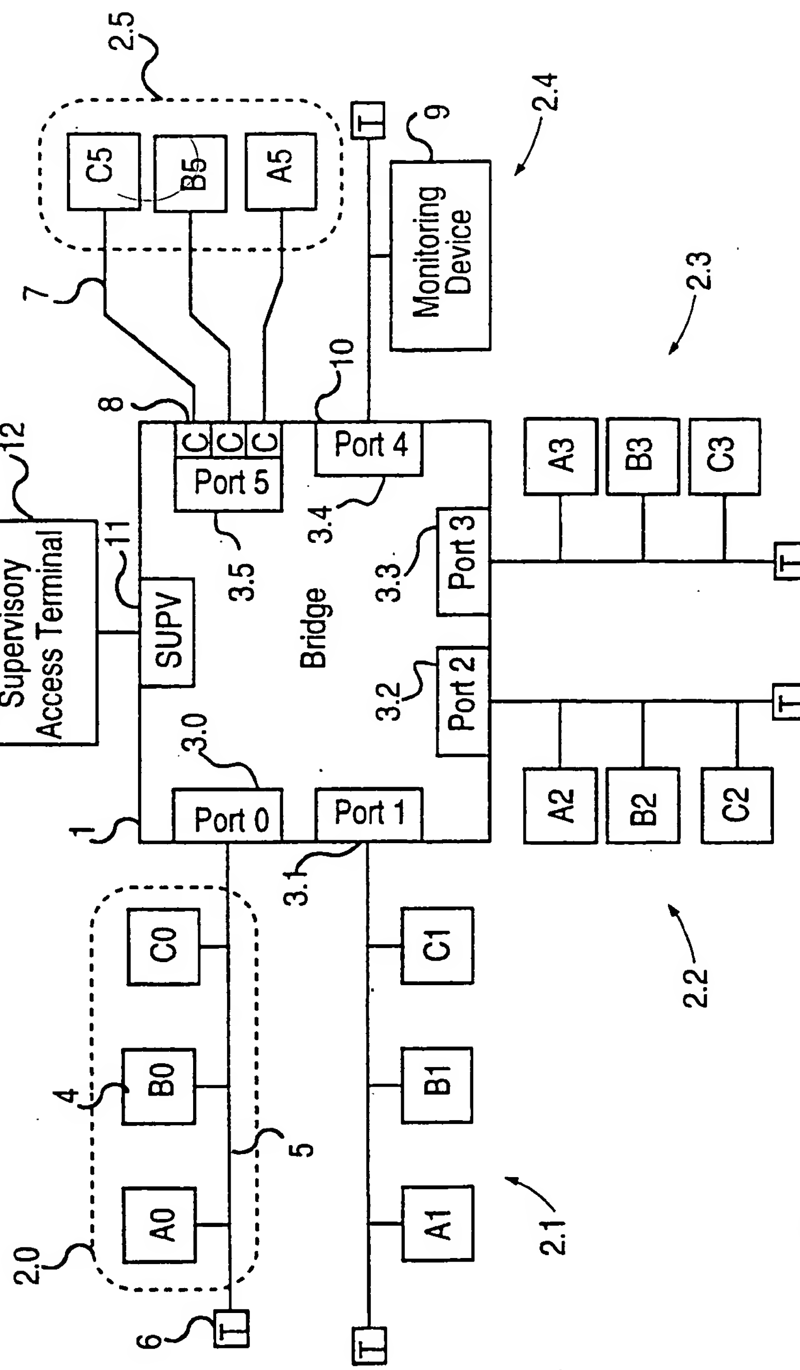

2.5
C5
B5
A5
T
9
2.4
Monitoring Device
7
2.3
10
8
C
C
C
Port 4
Port 5
12
A3
B3
C3
3.4
Supervisory Access Terminal
11
3.5
3.3
Port 3
T
SUPV
Bridge
3.2
Port 2
T
3.0
A2
B2
C2
1
Port 0
Port 1
3.1
C0
C1
2.2
B0
4
B1
5
A0
A1
2.1
2.0
6
T
T

Figure 1

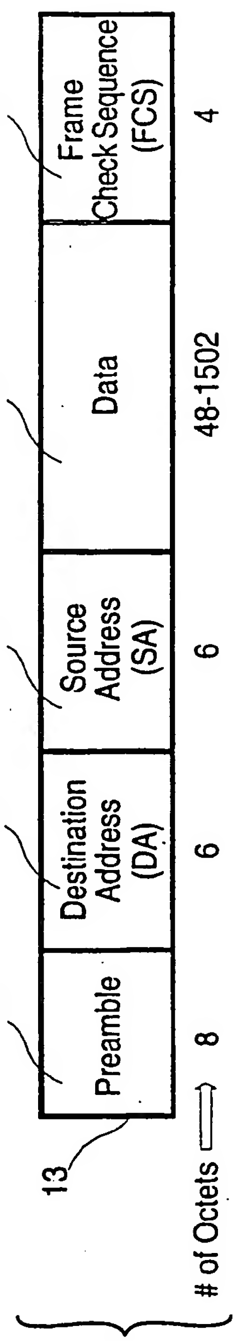

13
14
Preamble
15
Destination Address (DA)
16
Source Address (SA)
17
Data
18
Frame Check Sequence (FCS)
# of Octets
8
6
6
48-1502
4

Figure 2

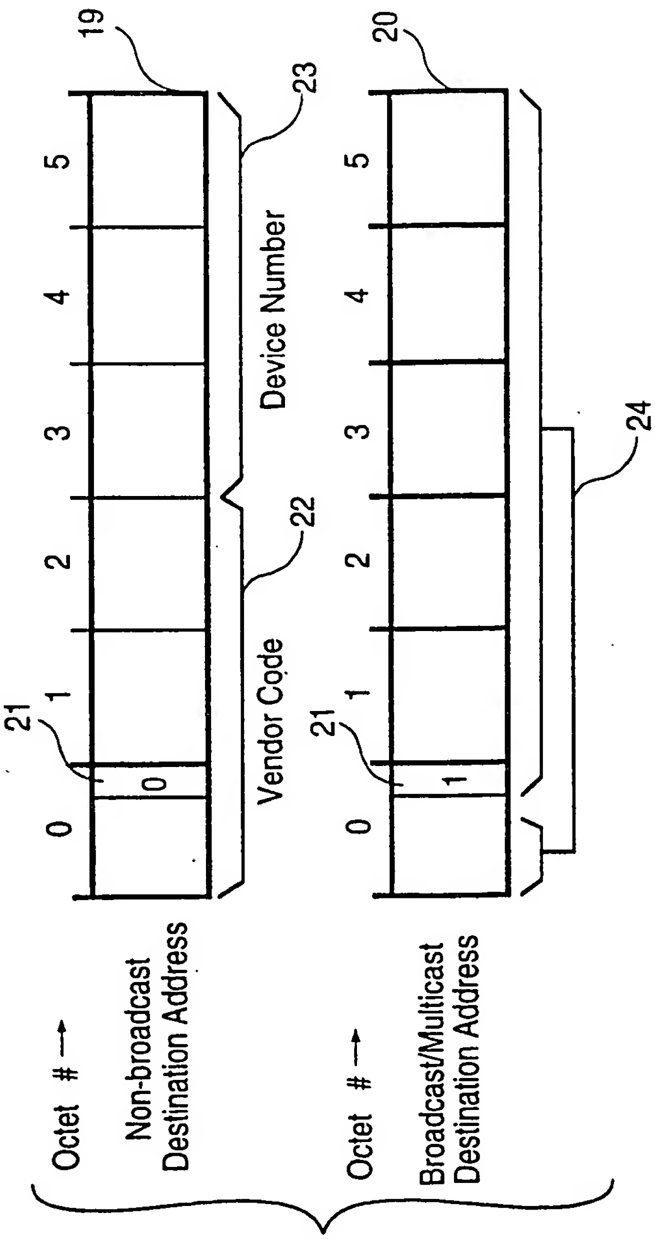

Octet # →
Non-broadcast Destination Address
Octet # →
Broadcast/Multicast Destination Address
0
1
2
3
4
5
Vendor Code
Device Number
19
20
21
22
23
24

Figure 3

25 28 Bridging Table Entry 26 27

Station Address	Port Number
A0	0
B0	0
C0	0
A1	1
B1	1
C1	1
A2	2
B2	2
C2	2
A3	3
B3	3
C3	3
A5	5
B5	5
C5	5

Figure 4

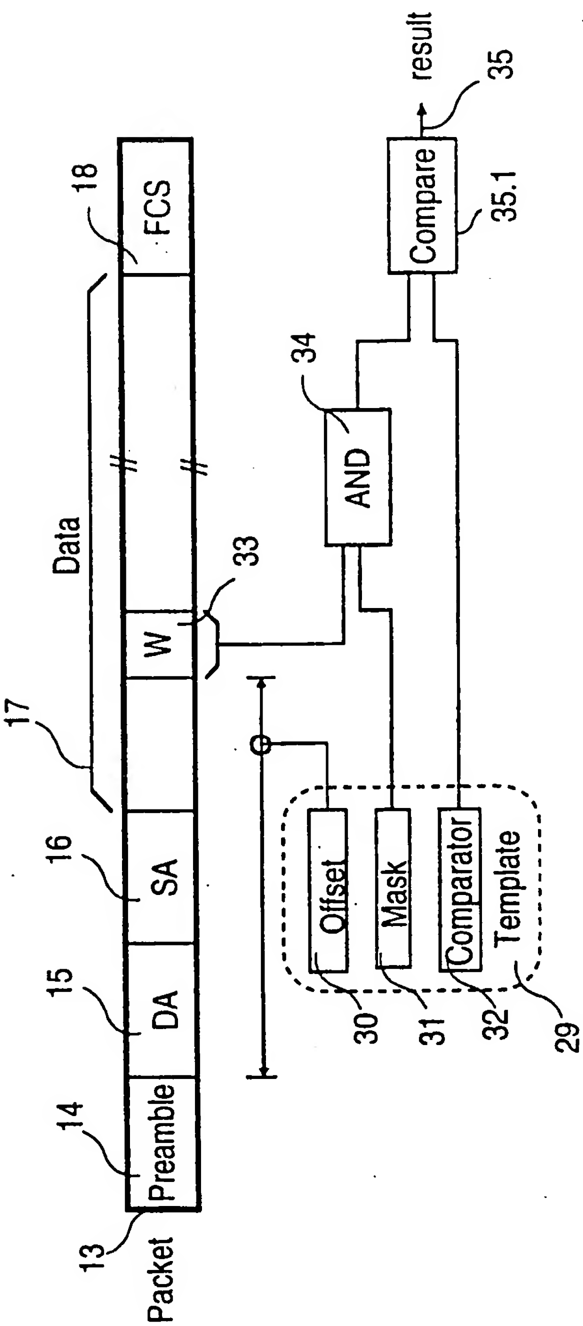

Packet
13
Preamble
14
DA
15
SA
16
17
Data
W
33
FCS
18
AND
34
Compare
35.1
35
result
Offset
Mask
Comparator
Template
30
31
32
29

Figure 5

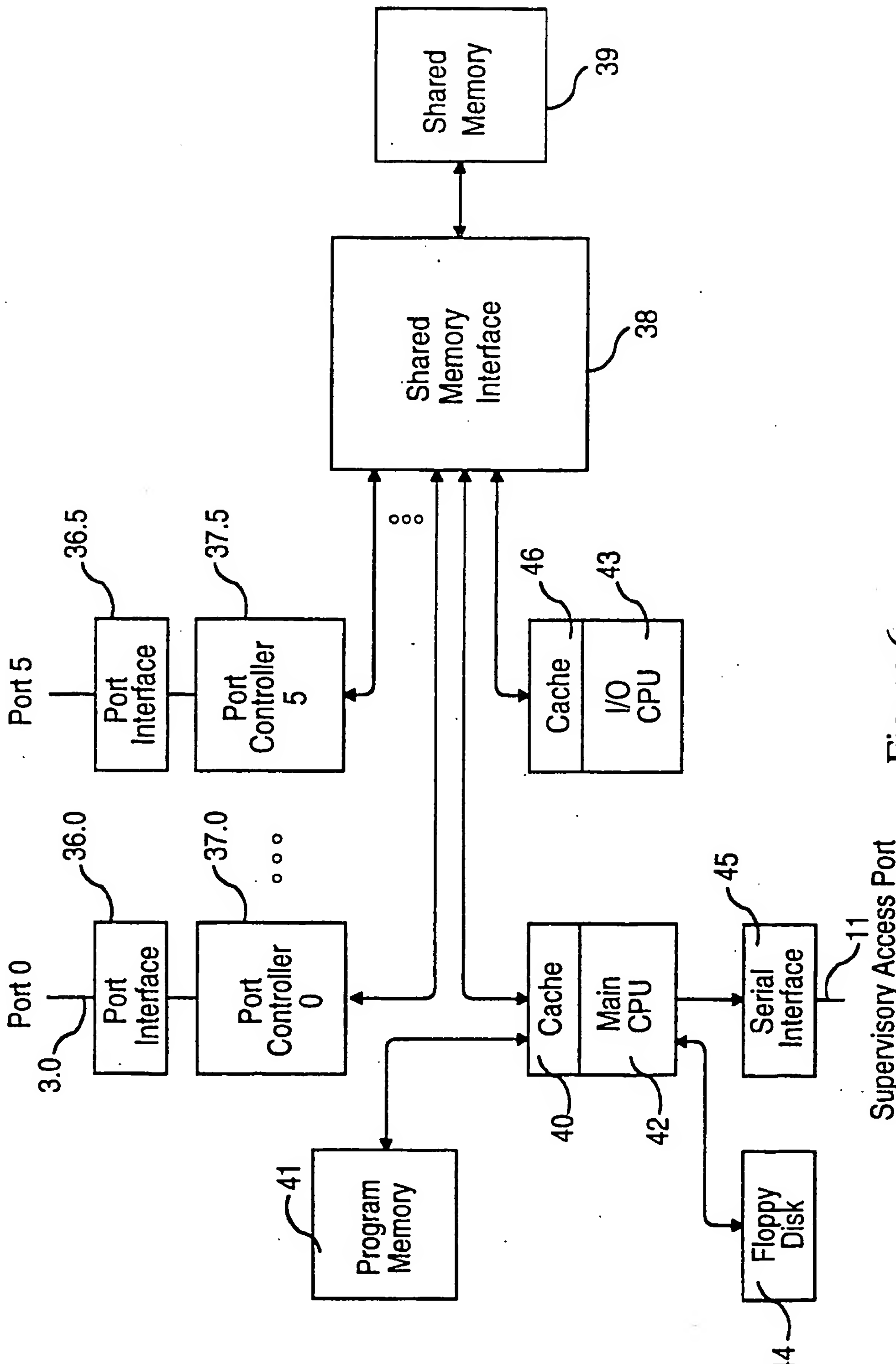

Shared Memory
39
Shared Memory Interface
38
Port 5
Port Interface
36.5
Port Controller 5
37.5
Cache
46
I/O CPU
43
Port 0
3.0
Port Interface
36.0
Port Controller 0
37.0
Cache
40
Main CPU
42
Serial Interface
45
11
Supervisory Access Port
Program Memory
41
Floppy Disk
44

Figure 6

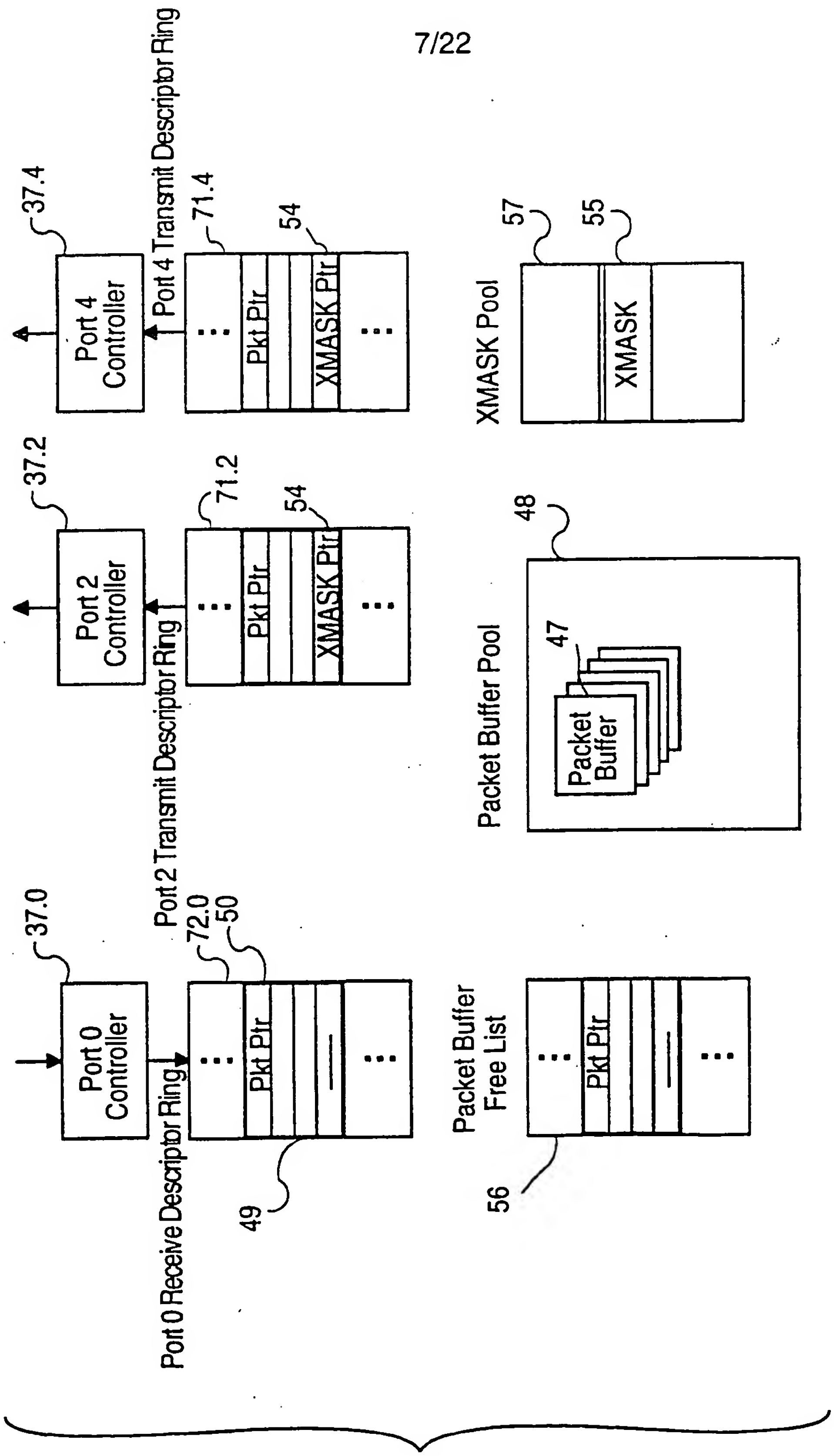
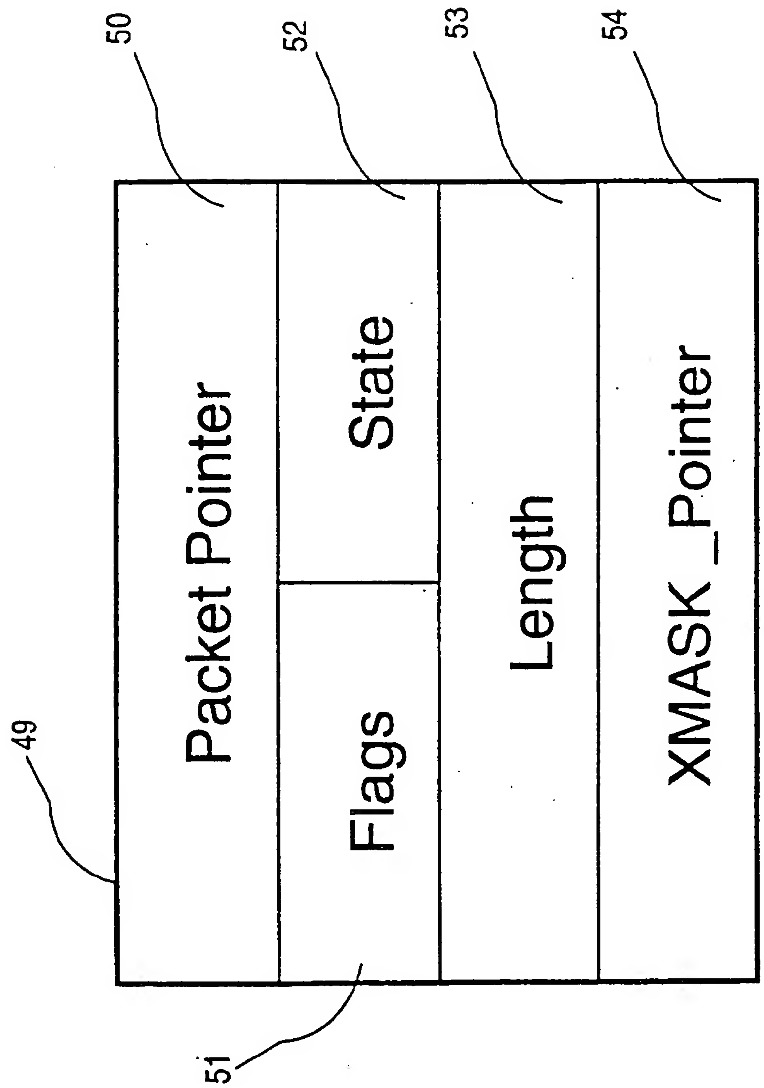

37.0
Port 0 Controller
Port 0 Receive Descriptor Ring
72.0
50
Pkt Ptr
49
37.2
Port 2 Controller
Port 2 Transmit Descriptor Ring
71.2
54
Pkt Ptr
XMASK Ptr
37.4
Port 4 Controller
Port 4 Transmit Descriptor Ring
71.4
54
Pkt Ptr
XMASK Ptr
Packet Buffer Free List
Pkt Ptr
56
Packet Buffer Pool
48
47
Packet Buffer
XMASK Pool
57
55
XMASK

Figure 7



49
50
52
53
54
51
Packet Pointer
Flags
State
Length
XMASK _Pointer

Figure 8

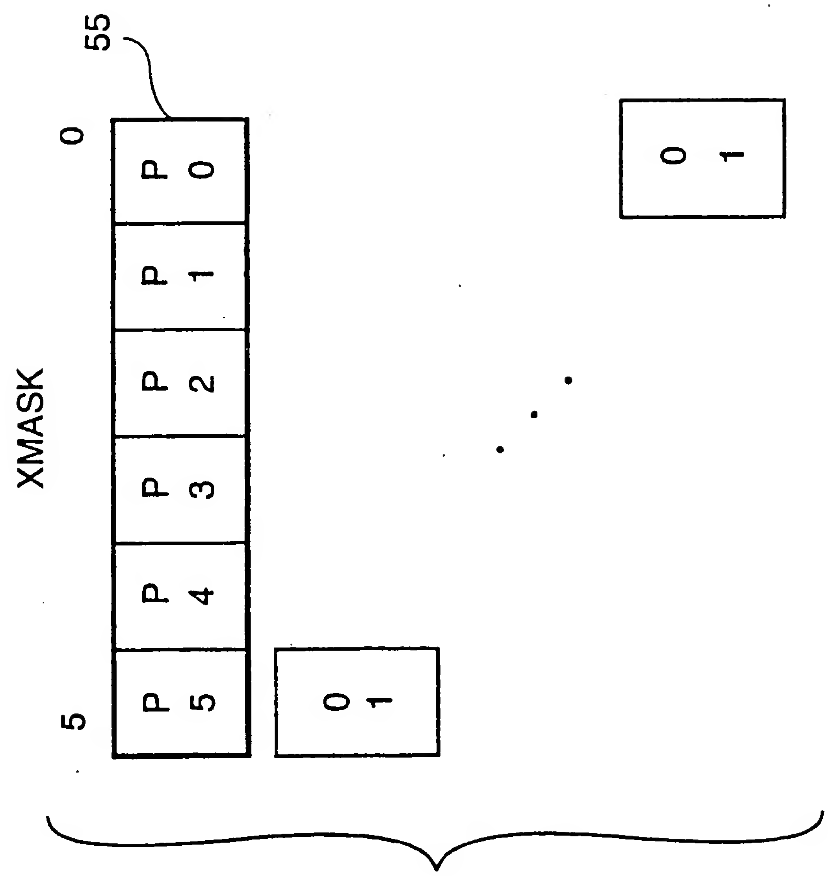


Figure 9

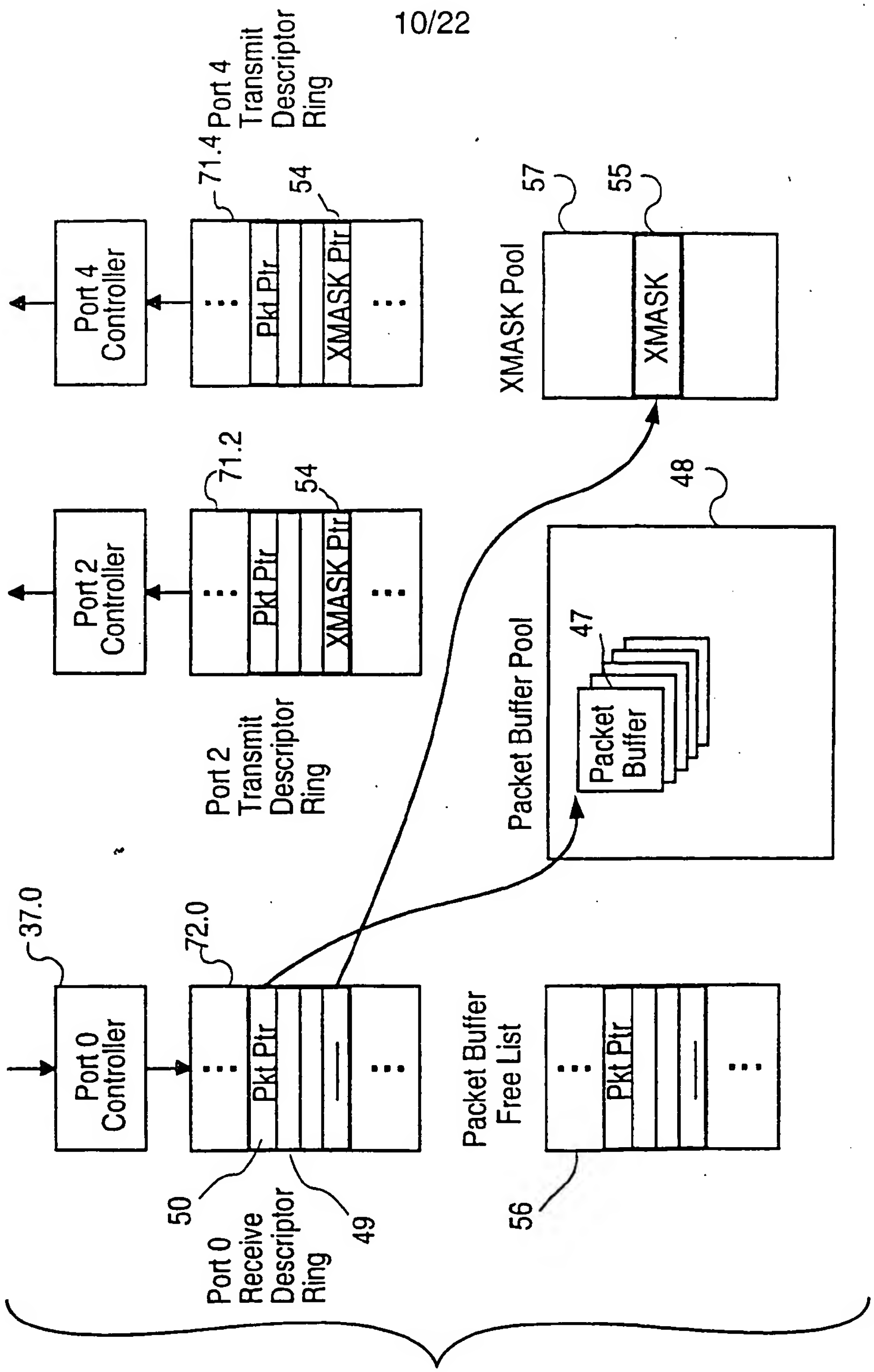

Port 0 Controller
37.0
Port 0 Receive Descriptor Ring
72.0
Pkt Ptr
50
49
Port 2 Controller
Port 2 Transmit Descriptor Ring
71.2
Pkt Ptr
XMASK Ptr
54
Port 4 Controller
Port 4 Transmit Descriptor Ring
71.4
Pkt Ptr
XMASK Ptr
54
Packet Buffer Free List
Pkt Ptr
56
Packet Buffer Pool
Packet Buffer
47
48
XMASK Pool
XMASK
57
55

Figure 10A

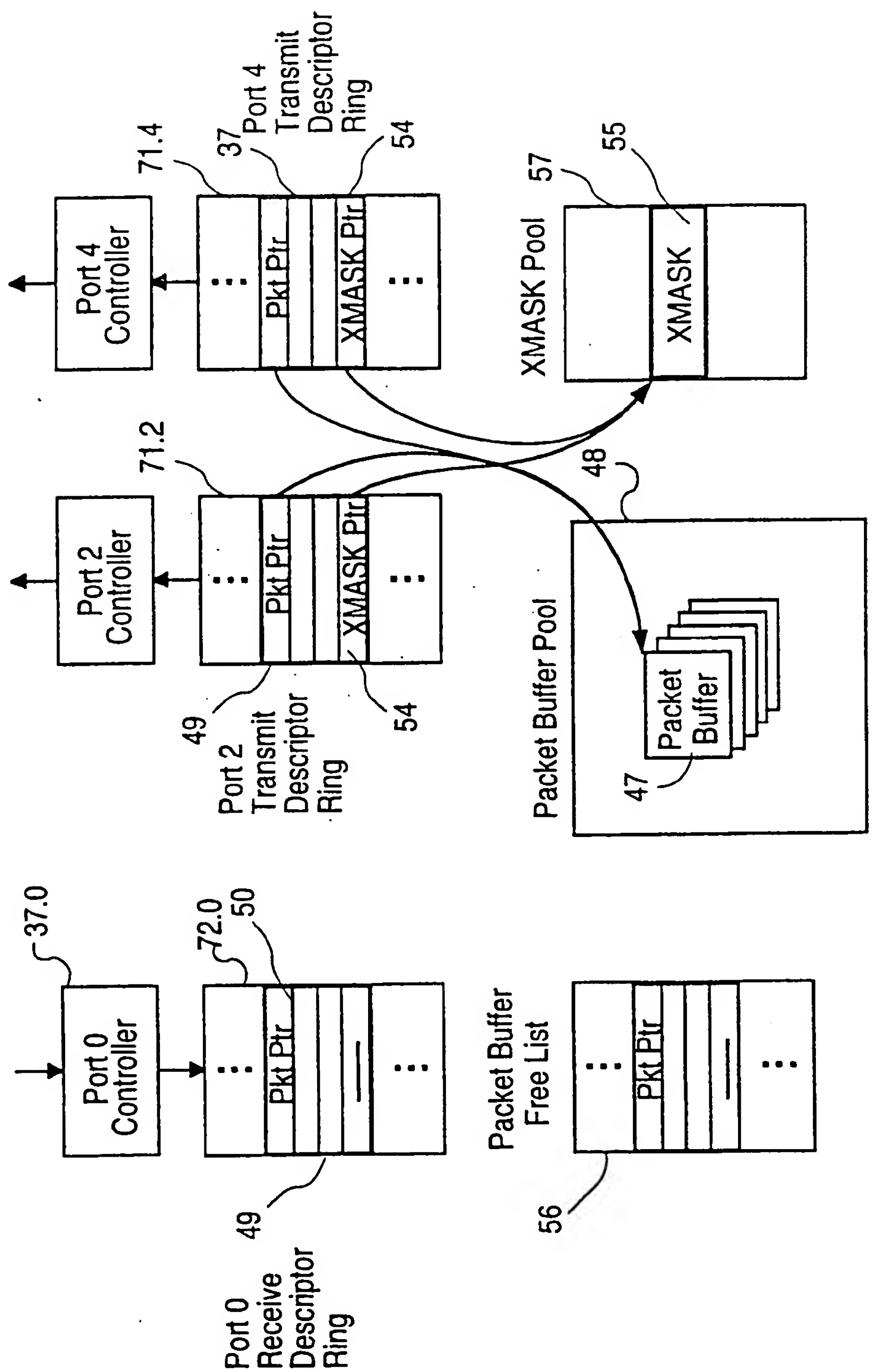

Port 0 Controller
37.0
72.0
50
Pkt Ptr
49
Port 0 Receive Descriptor Ring
Packet Buffer Free List
Pkt Ptr
56
Port 2 Controller
71.2
Pkt Ptr
XMASK Ptr
49
Port 2 Transmit Descriptor Ring
54
Port 4 Controller
71.4
37
Port 4 Transmit Descriptor Ring
Pkt Ptr
XMASK Ptr
54
Packet Buffer Pool
48
Packet Buffer
47
XMASK Pool
57
55
XMASK

Figure 10B

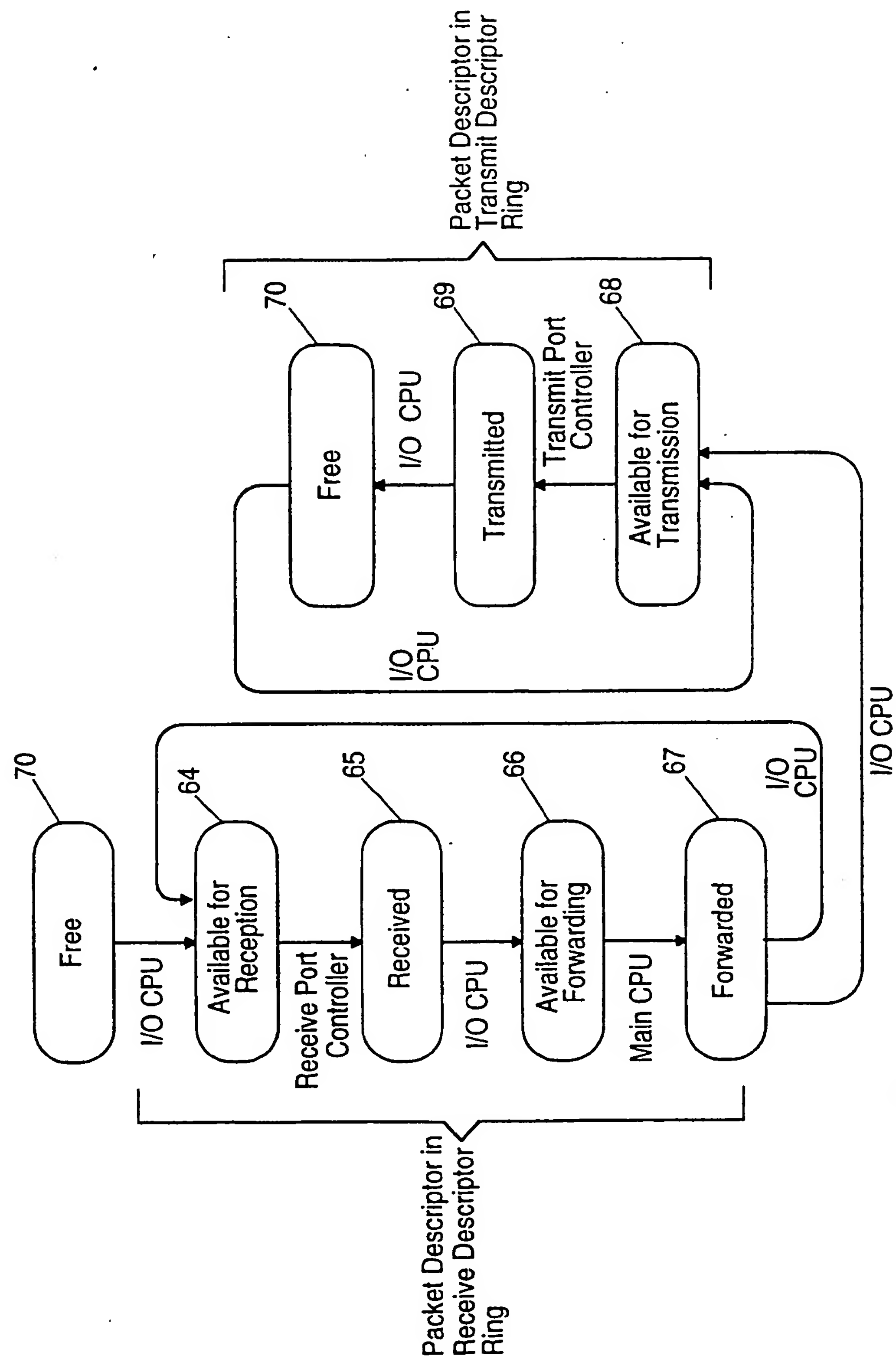

Packet Descriptor in Transmit Descriptor Ring
70
Free
I/O CPU
69
Transmitted
Transmit Port Controller
68
Available for Transmission
I/O CPU
70
Free
I/O CPU
64
Available for Reception
Receive Port Controller
65
Received
I/O CPU
66
Available for Forwarding
Main CPU
67
Forwarded
I/O CPU
I/O CPU
Packet Descriptor in Receive Descriptor Ring

Figure 11

RPORT \ XPORT	0	1	2	3	4	5
0	000000	000010	000100	001000	000000	100000
1	000001	000000	000100	001000	000000	100000
2	000001	000010	000000	001000	000000	100000
3	000001	000010	000100	000000	000000	100000
4	000000	000000	000000	000000	000000	000000
5	000001	000010	000100	001000	000000	000000

Figure 12

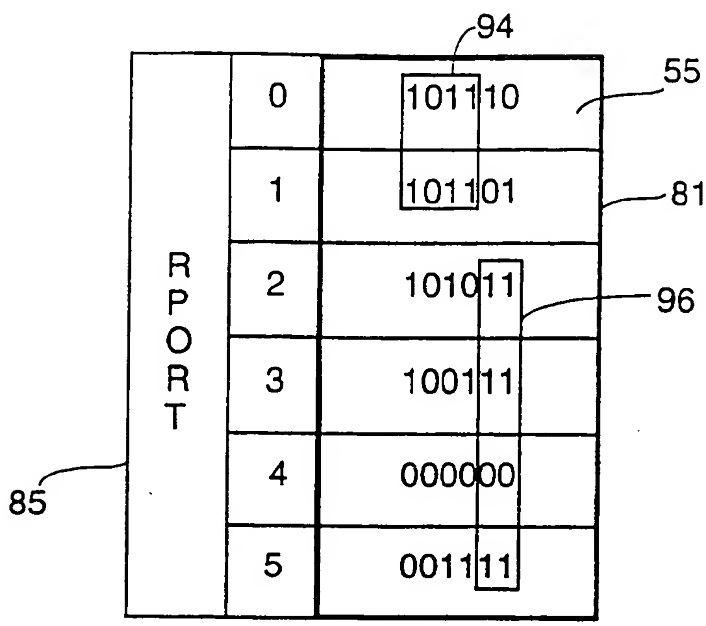

94
55
81
96
85
R P O R T
0
101110
1
101101
2
101011
3
100111
4
000000
5
001111

Figure 13

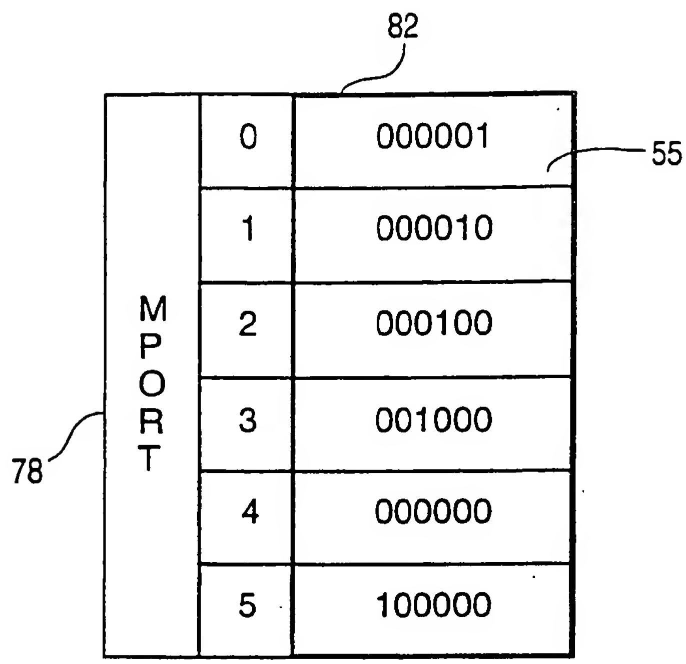

82
55
78
MPORT
0
000001
1
000010
2
000100
3
001000
4
000000
5
100000

Figure 14

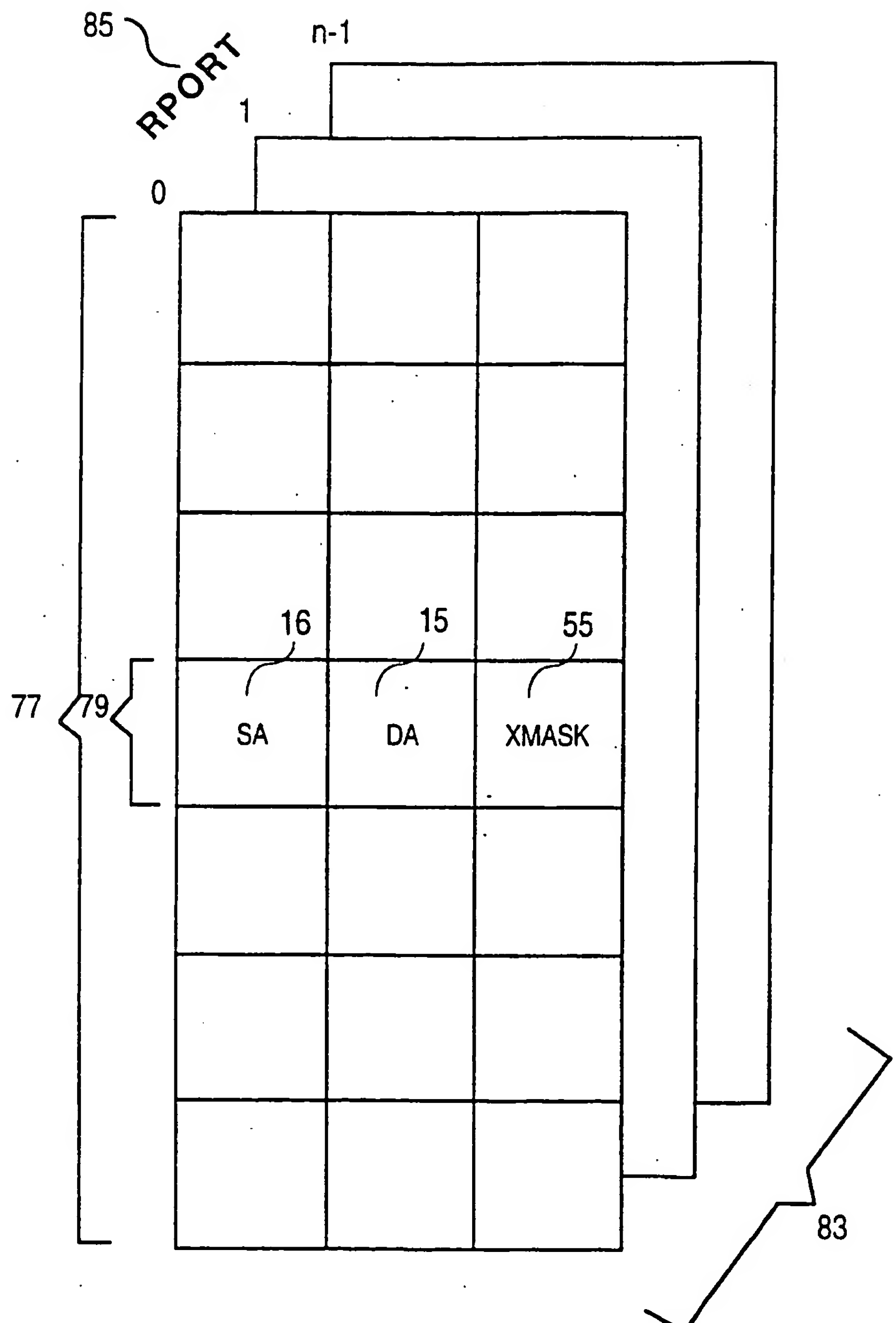
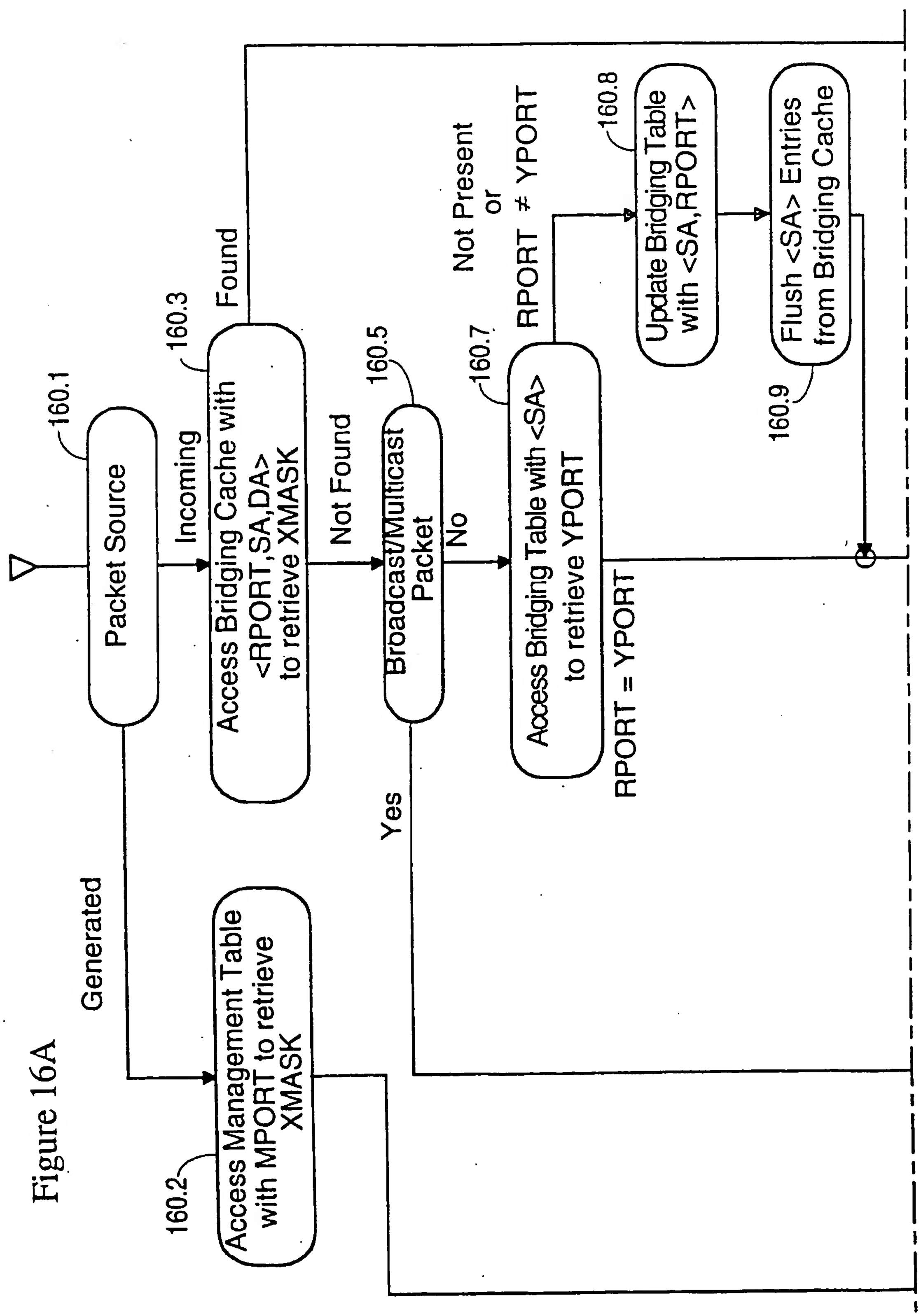


Figure 15



Packet Source
160.1
Incoming
Generated
Access Bridging Cache with <RPORT,SA,DA> to retrieve XMASK
160.3
Found
Not Found
Broadcast/Multicast Packet
160.5
No
Yes
Access Bridging Table with <SA> to retrieve YPORT
160.7
Not Present or RPORT ≠ YPORT
RPORT = YPORT
Update Bridging Table with <SA,RPORT>
160.8
Flush <SA> Entries from Bridging Cache
160.9
Access Management Table with MPORT to retrieve XMASK
160.2

Figure 16A

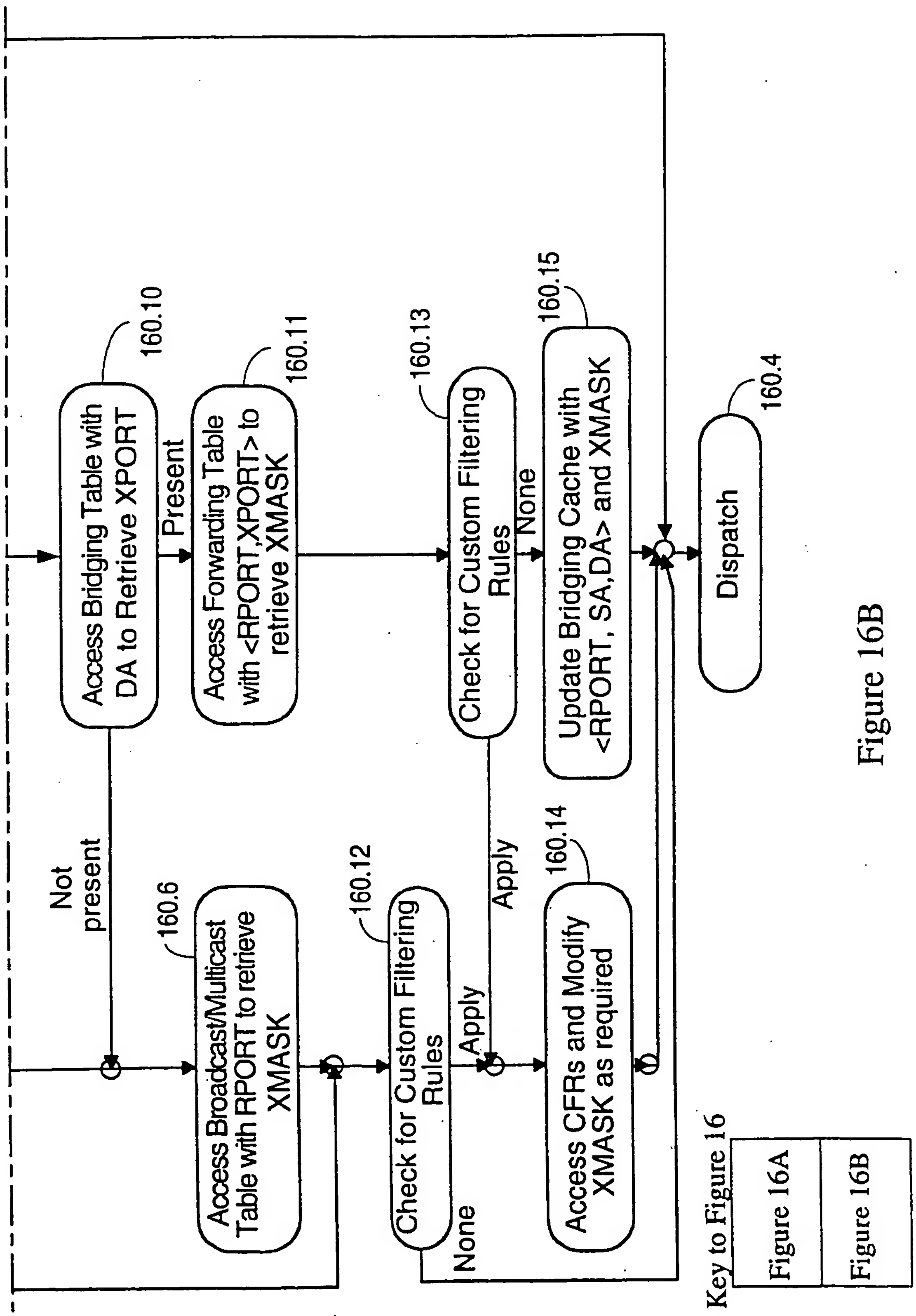

Access Bridging Table with DA to Retrieve XPORT
160.10
Present
Not present
Access Forwarding Table with <RPORT,XPORT> to retrieve XMASK
160.11
Check for Custom Filtering Rules
160.13
None
Apply
Update Bridging Cache with <RPORT, SA,DA> and XMASK
160.15
Dispatch
160.4
Access Broadcast/Multicast Table with RPORT to retrieve XMASK
160.6
Check for Custom Filtering Rules
160.12
Apply
None
Access CFRs and Modify XMASK as required
160.14
Key to Figure 16
Figure 16A
Figure 16B

Figure 16B

86

		XPORT					
		0	1	2	3	4	5
RPORT	0	000000	000010	000100	001000	000000	100000
	1	000001	000000	000100	001000	000000	100000
	2	010001	010010	010000	011000	010000	110000
	3	000001	000010	000100	000000	000000	100000
	4	000000	000000	000000	000000	000000	000000
	5	000001	000010	000100	001000	000000	000000

55 60 80 85

Figure 17A

RPORT	0	101110
	1	101101
	2	111011
	3	100111
	4	000000
	5	001111

55 61 81 85

Figure 17B

86

		XPORT					
		0	1	2	3	4	5
RPORT	0	000000	000010	010100	001000	000000	100000
	1	000001	000000	010100	001000	000000	100000
	2	000001	000010	000000	001000	000000	100000
	3	000001	000010	010100	000000	000000	100000
	4	000000	000000	010000	000000	000000	000000
	5	000001	000010	010100	001000	000000	100000

55 60 80 85 73

Figure 18A

63 62

RPORT	0	111110
	1	111101
	2	101011
	3	110111
	4	000000
	5	011111

55 61 81 85

Figure 18B

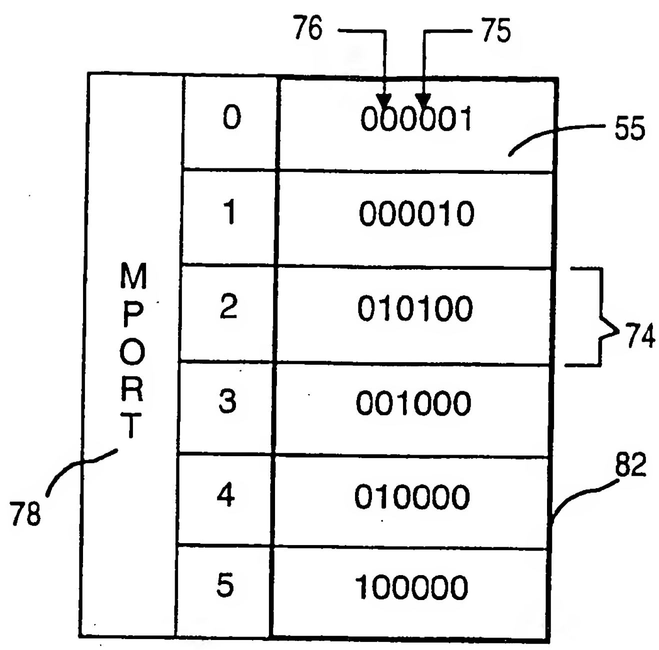

76
75
0
000001
55
1
000010
M
P
O
R
T
2
010100
74
3
001000
82
4
010000
78
5
100000

Figure 19

86

		XPORT					
		0	1	2	3	4	5
RPORT	0	000000	000010	000100	001000	000000	100000
	1	000001	000000	000100	001000	000000	100000
	2	000001	000010	000000	011000	000000	100000
	3	000001	000010	000100	000000	000000	100000
	4	000000	000000	000000	000000	000000	000000
	5	000001	000010	000100	001000	000000	000000

55 83 80 85

Figure 20A

63 62

RPORT	0	101110
	1	101101
	2	111011
	3	100111
	4	000000
	5	011111

55 61 81 85

Figure 20B

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US94/07082

A. CLASSIFICATION OF SUBJECT MATTER

IPC(5) :H04L 12/46
US CL :370/85.13, 60
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 370/85.13, 60, 85.14, 94.3; 340/825.06, 825.07

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X,P	US, A, 5,274,631 (BHARDWAJI) 28 December 1993, col. 7, lines 3-36.	1-6, 9-12, 14-15, 20-24, 25-29, 32
X	US, A, 4,817,080 (SOHA) 28 May 1989, col. 3, line 14 to col. 5, line 11.	1-12, 14-15, 18, 20-24, 26-29, 32

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
15 AUGUST 1994	OCT 06 1994
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231	Authorized officer HUY D. VU
Facsimile No. (703) 305-3230	Telephone No. (703) 305-4703